THE
GEOLOGICAL MAGAZINE
VOLUME LXX.

No. IX.—SEPTEMBER, 1933.

ORIGINAL ARTICLES.

The "Throw" of a Fault.

With illustrations from the Aberystwyth Grits.

By John Challinor, M.A., F.G.S.
(University College of Wales, Aberystwyth.)

(PLATE XXII.)

WHEN a bedding-surface is faulted, a large number of quantities, of more or less significance, may be considered.

The elements involved are: (1) the fault-surface, (2) the net relative movement along it, (3) the bedding-surface, and (4) the surface of outcrop or measurement.

The first two of these are inherent in the fault itself; the position and form of the fault-surface and the movement along it being the result of a tendency caused by earth-stresses and controlled (to some extent) by the structure of the rocks on which these stresses are acting.

The effects of a fault (of given surface and movement) in displacing the bedding-surfaces will vary with the direction and amount of dip (simply, the "dip") of these bedding-surfaces. If the surfaces are parallel, the effects on one will be the same as those on any other. Finally, these effects (as also the dip of the fault-surface and the dip of the bedding-surfaces) will be reflected in the outcrops; and measurements on the surface of outcrop (or on a plane of projection of it, or indeed on any surface real or imaginary) will vary with the direction and amount of slope of this surface. Outcrop, as such, will not be considered in the present argument; except in so far as it is implied in the consideration of horizontal and vertical sections. Matters may also be simplified by taking the bedding-surfaces and fault-surface to be planes; and by taking the net movement to be uniform over the part of the fault-surface involved. Such regularity is no doubt quite exceptional, but its assumption allows a standard general case to be considered.

The more significant linear and angular quantities may be tabulated as follows :—

(1) The (horizontal) direction of dip of the fault-plane. This gives, at right-angles to it, the strike—" fault-strike ".

(2) The amount of (true) dip of the fault-plane—" fault-dip ".

(3) The net relative movement along the fault-plane. This may have a component in any direction. Four significant directions lying in the fault-plane are :—

(3*a*) The strike of the fault-plane—" strike-slip ".

(3*b*) The dip of the fault-plane—" dip-slip ".

(3*c*) Parallel to the trace of the bedding-plane on the fault-plane—" trace-slip ".

(3*d*) At right-angles to the trace of the bedding-plane on the fault-plane—" perpendicular slip ".

Of these the first two appear to be the more important. Three other significant directions are :—

(3*e*) The vertical.

(3*f*) The horizontal direction at right-angles to the strike of the fault-plane.

(3*g*) Normal to the bedding-plane (= 6*d*).

(4) The (horizontal) direction of dip of the bedding-plane. This gives also the strike (at right-angles).

(5) The amount of dip of the bedding-plane.

(5*a*) The true dip.

(5*b*) The apparent dip in the direction of strike of the fault-plane.

(6) The distance between the surfaces of the two parts of the disrupted bedding-plane (including their imaginary continuations across the fault-plane).

This may be measured in any direction. Four significant directions are :—

(6*a*) The vertical—" vertical separation ".

(6*b*) The horizontal direction at right-angles to the strike of the bedding-plane—" normal horizontal separation ".

(6*c*) The horizontal direction parallel to the strike of the fault-plane.

(6*d*) Normal to the bedding-plane—" perpendicular separation ".

(7) The distance between the disrupted edges of the bedding-plane.

This may be measured in any direction lying in the fault-plane, the more significant being :—

(7*a*) At right-angles to the strike of the fault-plane. And this last quantity may have a component in any direction, the two most significant being :—

(7*b*) The vertical—" throw ".

(7*c*) The horizontal direction at right-angles to the strike of the fault—" heave ".

This paper does not attempt a systematic survey of fault-quantities and the above list is given merely as a background from which certain items can be picked out for consideration in the discussion which follows.

Amongst the voluminous literature dealing with faults, two works may be specially mentioned. They discuss (with illustrative figures) this important question of the relation between these various fault-displacement quantities, and give many references to previous literature. The first of these is the "Report on the Nomenclature of Faults", drawn up by a committee of the Geological Society of America and published in 1913,[1] and the second the new edition of Willis' *Geologic Structures.*[2] The terms used in the *Report* are quoted in the above list of significant quantities.

To approach now the particular point with which this paper deals—the meanings and implications surrounding the term "throw"—consider first the projection of the fault-plane on to a vertical plane trending in the direction of fault-strike, and also a vertical section at right-angles to the fault-strike (Figs. 1 and 2).

In Fig. 1 MNPQ represents such a projection of part of a fault-plane. Before faulting a bedding-plane may be imagined as intersecting the potential fault-plane so that AB is part of the line of intersection of the two planes. During faulting the rocks on the near side of the fault may be imagined as having moved while those on the far side remained still, so that there are now two traces of the bedding-plane with the fault-plane; suppose that the point A has moved to A^1 and B to B^1. It might equally well be imagined that the near side remained still while on the far side the point A^1 moved to A; or that both sides have moved. The two traces represent net relative movement and we are concerned only with such movement. AX represents the vertical component

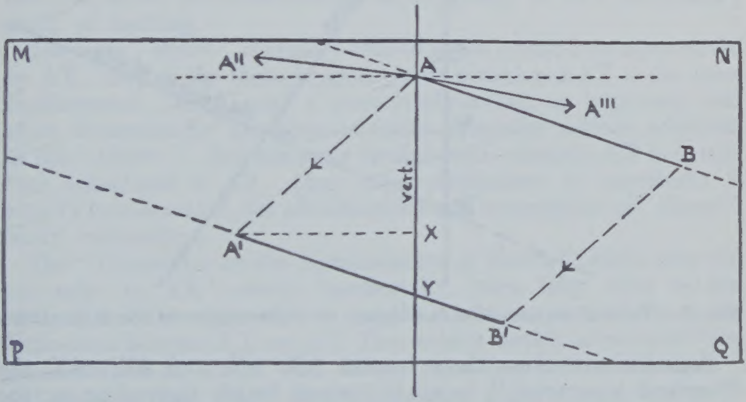


Fig. 1.—Projection of a fault-plane on to a vertical plane trending in the direction of fault-strike.

---

[1] H. F. Reid and others: "Report of the Committee on the Nomenclature of Faults," *Bull. Geol. Soc. America*, xxiv, 1913, 163.

[2] B. Willis and R. Willis: *Geologic Structures*, 2nd ed., 1929.

of this movement (3*e*). AY is the vertical component of the distance between the disrupted edges of the bedding-plane measured in a plane at right-angles to the strike of the fault-plane (7*b*). It should be noted that the points X and Y are not on the fault-plane, but on the vertical line through A.

In Fig. 2 AX and AY are the same as in Fig. 1. AZ is the vertical distance between the two parts of the disrupted bedding-plane (6*a*).

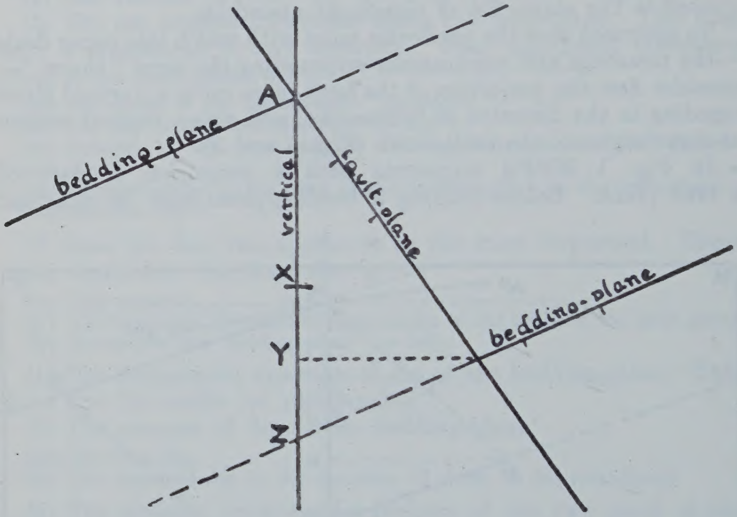


Fig. 2.—Vertical section of a fault-plane at right angles to the fault-strike.

Consider now these three lengths AX, AY, and AZ. AZ, the "vertical separation", is an important length depending on the component of movement 3*g*, which is the same in quantity as the "perpendicular separation" (6*d*) and the dip of the bedding-plane (5*a*). Given these values AZ is constant. It could be obtained from a contoured map by comparing the strike lines of the bedding-plane on one side of the fault with the strike lines of the same plane on the other. AY is the sum of AX and a length (XY) which depends on the component of movement 3*a* ("strike-slip") and the apparent dip of the bedding-plane (5*b*). It should be remembered that the length AY is obtained from a measurement made in one particular vertical plane only; the vertical distance between the dissevered edges varying according to the direction of section. AX, being a component of movement, is inherent in the fault. It causes the separation of bedding-planes and of disrupted edges.

These three lengths are therefore quite distinct and differ widely in the degree to which they are fundamental. But there appears to be considerable confusion between them, this being largely due to the fact that most works dealing with faulting consider only special cases in which these quantities, or at least two of them, are equal; and this without making it clear that they *are* special cases and that much of the discussion does not apply to the general case. The general case will be the usual case unless certain special cases are particularly liable to occur in nature. Strike-faulting may be to some extent a "favoured" case in this sense, and in most faults there is, probably, more vertical movement than movement parallel to the strike of the fault; but it seems likely that the great majority of faults are inclined faults oblique as regards direction and oblique as regards movement. Actual faults would no doubt always have, also, at least some degree of irregularity of surface and movement along it; but this does not affect the validity of the present argument. The correct interpretation of faults observed in the field should, surely, rest on an appreciation of the general and usual case, and not on an appreciation of special cases only however useful the consideration of these may be in a preliminary study of faulting.

The term "throw" is usually defined as the length here represented by AY. But of the three lengths above considered AY is the least fundamental. AZ, though a more fundamental, an important and often determinable quantity, is (quite properly) seldom admitted as the "throw". But the truly fundamental distance AX is hardly ever considered at all. (Any other component of movement is equally fundamental, but all definitions and conceptions of "throw" imply verticality.)

The "Committee on the Nomenclature of Faults", while they did not refer to AX[1] except incidentally, were fully alive to the distinction between these three lengths, and more particularly to the distinction between AX and AY. The authors frankly admit that "the generalization of 'throw' and 'heave' presents peculiar difficulties", and make it clear that "throw" (as they define it and as usually defined; that is, AY) is a mere geometrical result, on the bedding, of fault movement, and implies nothing definite (certainly nothing quantitative) about that movement itself. Later discussions make no such careful and important distinction as that made by the Committee, either stating or implying quite definitely that (for instance) the "downthrow" side of a fault refers both to a geometrical effect *and* to a component of actual movement. This is done even in such a thorough and precise discussion as that in *Geologic Structures.*[2]

The throw AY may be of paramount importance in practical mining, but appears to be by no means the most important fault-quantity to be considered in questions of theoretical geology. In the latter case the nameless AX is the quantity to be sought.

---

[1] In referring to these three lengths in a general way, the terms AX, AY, and AZ will be used here.

[2] pp. 127–8.

The term "throw" is applied to two quite different quantities, and is almost universally made to do duty for both at the same time. But it seems that "throw" should be *either* a geometrical effect (AY) *or* an actual movement (AX). In certain special cases these two quantities are the same in direction and amount; in the general case they are different in amount and may be in either the same or the opposite direction—more often than not, no doubt, in the same direction. The terms "upthrow" and "downthrow" (and "normal" and "reversed") in so far as they are made to imply the direction of up-and-down movement (and they usually are made to imply this) refer not to "throw" as usually defined, but to AX or to the "dip slip" (3*b*).

The fact is, it is usually impossible, merely from a knowledge of resulting geometrical relations, to state with certainty on which side of a fault there has been relative upward or downward movement. The possibility of making a wrong inference is at once obvious on turning again to Fig. 1. If the movement along the fault-plane makes a smaller angle with the horizontal than the apparent dip of the beds (5*b*) in the direction of strike of the fault (that is, if A moves in a direction such as AA^{11} or AA^{111} in Fig. 1), AY (and AZ) will give a "downthrow" on the side along which there has been relative upward movement. This is not a special case, but represents a set of cases which may form a considerable proportion of the possible cases when the beds have a steep, or moderately steep, dip.[1]

The uncertainty as to the recognition (from the geometry of faulting) of the side of relative downward movement carries with it uncertainty as to the recognition (again, when the fault-geometry only is being considered) of the distinction between compressional and tensional forces responsible for faulting. Far-reaching theoretical conclusions may depend on the recognition of this distinction; thus the confusion about the implication of the term "throw" appears to be a dangerous one.

The following are the special cases in which it appears that two, or all three, of these vertical lengths, AX, AY, and AZ, are equal:—

$AX = AY$ if the movement has no component parallel to the fault-strike or if the fault-strike is the same as the bedding-strike.

$AY = AZ$ if the fault-plane is vertical or if the fault-strike is at right-angles to the bedding-strike.

Therefore all three are equal if, with up-and-down movement only, the fault-plane is vertical or is a true dip-fault. All three are also equal, whatever the character of the movement, if the fault is a vertical strike-fault, or if the bedding is horizontal.

It is here suggested therefore that as the term "throw" should not be used for two quite separate quantities, and as it is probably more convenient to keep it for the geometrical quantity AY (as which it is usually defined,[1] whether or not it is at the same time made to refer to AX) then some other term should be applied to the very important (if difficult to discover) length AX, the vertical component of net relative movement along the fault-plane.

---

[1] Cf. *Geologic Structures*, fig. 78, p. 148.

In conclusion, I wish to express my thanks to my colleague, Mr. W. G. L. Sutton, for much help in elucidating the more mathematical aspects of this problem.

SOME ILLUSTRATIONS FROM THE ABERYSTWYTH GRITS.

The Aberystwyth Grit formation stretches along the Cardiganshire coast from Borth in the north to beyond Newquay in the south, a distance of some 30 miles, and displays a fine series of structural features in the cliffs and on the shore. It would perhaps be difficult to find better illustrations of fault-structures, in particular, than are provided here. They are of all sizes and varieties, and are made conspicuous by the very well-bedded nature of the rocks. The photographs forming Plate XXII were all taken within a distance of about 700 yards along the strip of coast (running approximately N.N.E.–S.S.W.) between Aberystwyth and Clarach Bay. They illustrate a few representative types of faults.

Fig. 1. This fault is exposed on the sides (and front) of a large projecting rock, and the sea has drilled a hole through it parallel to the general trend of the coast, taking advantage of the fault as a surface of weakness. The beds dip nearly uniformly at 35° in a direction E. 19° N.; and the fault is also practically a plane surface, dipping at 60° in a direction E. 20° N. It is thus very nearly a true strike-fault, though the divergence is clearly detected in plan on the shore on the far side of the rock. The view is taken from the south, and the fault is seen on one of the two vertical and parallel rock-faces which form what are practically both bedding-dip-sections and fault-dip-sections. The conspicuous grit-band on the right, which reaches the cliff-front at the top of the photograph, is the same as that which, on the left, meets the fault at the top of the cave. The fault is thus seen to be a reversed fault. The displacement of the bedding along the exposed line of the fault is 54 feet. As the section is vertical and at right-angles to the strike of the fault, AY and AZ can be measured directly. As the fault is a strike-fault AX = AY. We do not know what movement, if any, there has been parallel to the strike of the fault.

Fig. 2. The reversed strike-fault shown in Fig. 1 crops out on the wave-cut bench on the north side of the projecting rock for about 18 yards, and is then cut off, together with the uniformly-dipping beds it affects, by a well-marked dip-fault. To the north of this fault the beds are bent so that their strike is nearly

parallel to the strike of the fault where they meet it; but they gradually resume the general north-and-south strike some yards away. Near the fault on the north side the beds show signs of crumpling. Neither the strike-fault nor any particular beds on the south side have been matched on the north. The movement along this fault seems to have been large; and the behaviour of the beds on the north side seems to suggest that this side moved westwards, with consequent dragging of the beds near the fault, while the south side remained practically still; the fault being a "tear". The sea has eroded a shallow trench a yard or two wide immediately on the north side of the fault, and subaerial erosion has produced a conspicuous little gully in the sea-cliff behind. The view is taken looking east, towards the cliff. The slide-rule is placed across the fault. The shallow trench is mostly covered with loose stones, but one "escarpment" can be seen in the deflected beds. On the right (south) side of the fault, the beds are seen dipping away from the observer. AX, AY, and AZ are all unknown.

---

[1] Although C. K. Leith in his authoritative work *Structural Geology* (revised edition, 1923, 66) expressly defines "throw" as "net vertical displacement . . . the vertical component" [of movement]—i.e. as the length AX. The present writer has also defined it as such (in J. Platt and J. Challinor, *Simple Geological Structures*, 1930, 23).

Fig. 3 This photograph shows typical small scale faulting exposed on an irregular, sloping surface. The fault, which divides into two branches for a short distance, appears to be, for the greater part, approximately vertical or to have a steep dip to the right; but it tends to cross the thicker grit-bands at right angles instead of cutting straight through them obliquely. The downthrow side (in the geometrical sense) is everywhere on the right, so that the fault as a whole is a normal fault, though the left hand branch (which dips steeply to the left) is "reversed". A very small incipient fault is seen towards the right edge of the photograph. The beds dip at an angle of 55° in a direction E. 8° N. The surface of exposure has a general slope of about 60° in a S.W. direction, and the direction of view is approximately at right-angles to this surface. The conspicuous grit-band near the top of the photograph is 4½ inches thick. AZ and AY can be calculated, but AX is unknown. Incidentally, the bedding here (as is the case generally in the Aberystwyth Grits) shows well the characteristic "graded" structure.[1]

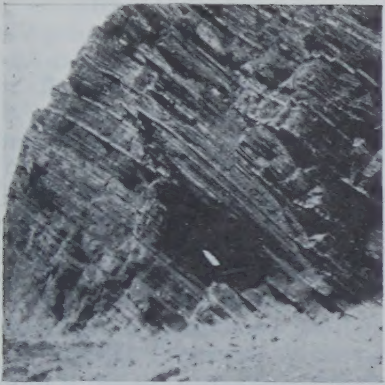
Fig. 4. The fault shown in this photograph is an example of a bedding-fault, probably the commonest type of fault in the Aberystwyth Grits. The rocks have slipped along a bedding-surface which thus becomes also the fault-surface. There is no displacement of outcrop, such a fault being detected only by slickenside-features; and, except for such indications as these features may give, there is no evidence of the direction of movement along the fault-plane. This bedding-fault-surface forms the steeply-sloping back of a projecting rock which is fast becoming an isolated "stack" by erosion. The surface has been alluded to in a previous paper.[2]

Fig. 5. This is an oblique view of a small part of the shore which

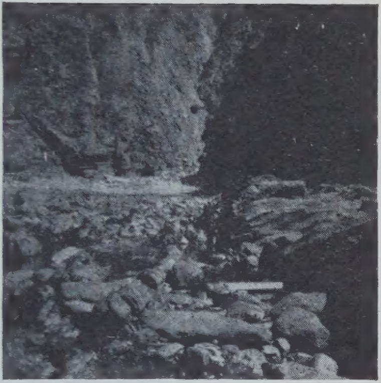
[1] E. B. Bailey, Geol. Mag., LXVII, 1930, 86.

[2] Geol. Mag., LXVI, 1929, 354.

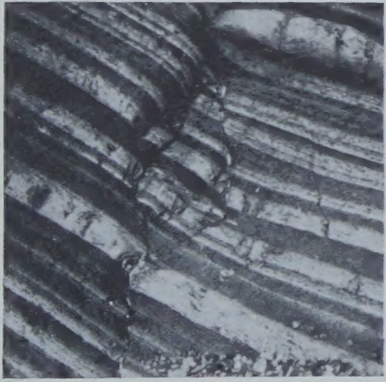
1



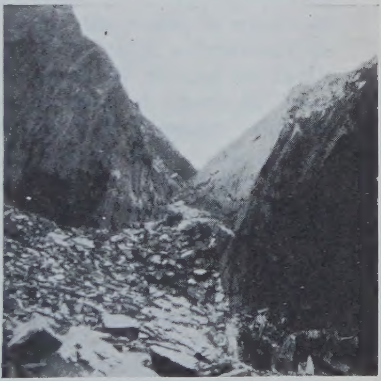
2



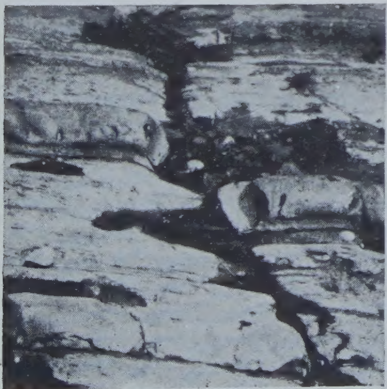
3



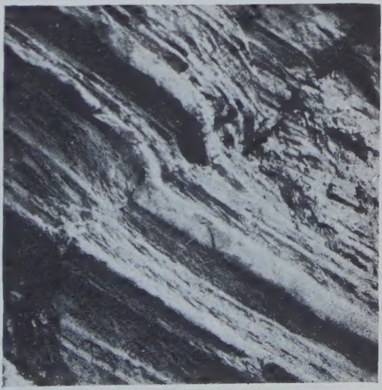
4



5



6



FAULTS IN THE ABERYSTWYTH GRITS.

[*To face p.* 392.

shows many fault-structures exposed in plan. This particular fault is an oblique fault, but curves slightly so as to become practically a dip-fault in the back part of the view. The fault itself is etched out as a detail of erosion, as are also the softer layers of the rocks it affects, so that both the fault and its effect are made conspicuous. A prominent grit band (4½ inches thick) forms a miniature " escarpment " by differential erosion. The dip of the beds here is 55°. It will be seen that the downthrow side is on the right (or the south side) and the fault appears to be steeply inclined to the right and is thus a normal fault. Although we thus have all essential information about the " geometry " of the fault, we do not know the direction of movement along the fault-surface except that it is within an angular range of a certain 180°. The right hand side of the fault may have dropped down relative to the left, or may have moved horizontally " forwards ", or may have been uplifted (together with a certain proportion of forward movement).

Fig. 6. This photograph shows an oblique fault (approximating more nearly to the strike than to the dip of the rocks) in section at the base of the cliff. The section is practically a bedding-dip-section. The beds dip at 30° in a direction S. 30° W. and the fault, though somewhat irregular, has a general dip of about 55° in a direction E. 30° N.; the dip of the fault being " against " the dip of the beds. The thick grit-band is 8 inches thick. AZ can be measured directly, but as the section is not at right-angles to the fault-strike we cannot measure the throw AY (though it can be calculated). The amount of AX is not known at all, nor is the side of relative downward movement known with certainty; but the way the beds tend to curve in the immediate neighbourhood of the fault seems to suggest that the left side has really moved relatively upwards along the fault.

Metagenesis in *Lepidocyclina* from the Eocene of Peru.

By J. U. Todd.

In December of 1932 a paper was published in the Geological Magazine (1)[1] dealing with a number of Tertiary orbitoidal foraminifera from N.W. Peru, which had been presented to the British Museum. During the examination of the material it was noticed that there were no forms present comparable to *Lepidocyclina R. Douvillei* Lisson in regard to the size of the embryonic apparatus, although a large number of the specimens had been collected from Lisson's type locality. All the forms examined from Mount Organos and from contemporaneous deposits in the neighbourhood proved to have a much smaller apparatus and were found to be identical with *Lepidocyclina peruviana* (Cushman) when compared with the type material in the Sedgwick Museum, Cambridge.

[1] The numbers in parentheses refer to Bibliography at end of article.

While the above-mentioned paper was in the press it became possible to examine a further collection of Tertiary rock samples from N.W. Peru which had been presented to the Sedgwick Museum by C. Barrington Brown. In this collection there were found to be a few forms which could be compared directly with *L. R. Douvillei* in regard to the size of the embryo and always closely associated with abundant *L. peruviana.* At first, from an examination of the external views, it was thought that only *L. peruviana* was present but when sections were made a few forms showed the larger embryo which was well outside the average range as given for that species by Todd and Wright-Barker (1), though it was evident that there was no sharp division between the two, but rather a gradual range.

A still more careful study of the exteriors again failed to show any means of differentiation, though a large number of specimens were examined. It thus appeared that only in the size of the embryo was there any distinction between the species, since other internal measurements did not differ to any marked degree.

Vaughan (2), p. 797, and Nuttall (3), p. 104, both state that *L. peruviana* is a synonym of *L. R. Douvillei,* an opinion with which Miss Gorter and Van der Vlerk disagree (4), p. 105, pointing out that *L. peruviana* has a flange and well-developed pillars, whilst *L. R. Douvillei* has not these characters. In the description of *L. peruviana* Todd and Barker (1) point out that there may be a variation in the shape of the test, in that it may be domed with a flange or robustly lenticular, whilst the pillars are very irregular in their formation, being absent in some cases and strongly developed, i.e., up to 180μ thick at the periphery, in other cases. Even in a single specimen the formation of the pillars is not regular. In this respect Hofker says (5), p. 102, " Fossil forms such as *Orbitolites*, *Lepidocyclina*, etc., . . . show a high variation of their secondary chalk-deposits. So it is to fear that different forms of a species of these fossil groups will show different development of their pillars, columns and even spines."

Miss Gorter and Van der Vlerk describe *L. R. Douvillei* as having an embryonic apparatus varying from 410-530μ in diameter whilst H. Douvillé (6), p. 36, claims that it should be very near to *L. trinitatis* H. Douvillé and perhaps does not show any specific distinction from it. Tobler (7) disagrees with the latter opinion on account of the fact that *L. trinitatis*, described as having an embryonic apparatus varying in diameter from 310–480μ, is characterized by its strongly marked pillars, whereas *L. R. Douvillei* has none.

A study of Lisson's paper (8) shows that he describes a " Forma joven " and a " Forma adulta " of *L. R. Douvillei* but that the " Forma joven " has a much smaller embryo than the " Forma adulta ". This opinion of a young and adult stage of the same species must, of course, be discarded, since the embryo, being the first stage of growth and surrounded by a thick wall, cannot alter its size during growth. This error is of the same kind as that made by

Munier-Chalmas (see Lister (9), p. 404), who concluded that the microspheric form was built from a megalospheric form by the formation of a spiral set of chambers to the centre of the shell after the shell had come to the size of the normal megalospheric form.

If, therefore, these two forms are to be taken as only one species it appears that the present method of making specific differences by means of the embryonic apparatus must be discarded, since there is a possible range of about 300μ in this species, i.e. from 204μ as given by Todd and Barker to 530μ as given by Miss Gorter and Van der Vlerk. It seems, however, that should the theory of Trimorphism, put forward by Hofker, be taken into consideration the differences could be explained. Hofker has done much work on this theory as applied to the smaller foraminifera, and has already applied it to the larger foraminifera in the case of *Orthophragmina* (*Discocyclina*) *advena* Cushman (10). The word "Trimorphism" is, however, rather unfortunate since it implies that there should be recognized three forms. In many cases this seems to be true, but in other cases the two megalospheric forms cannot be distinguished by means of the outer test. To replace the word "Trimorphism" a word is needed that only implies three modes of reproduction, which is the main base of the theory, and possibly the word "Metagenesis" (as used by Hofker (5), p. 92. . . . We have here a typical case of metagenesis . . .") would be the better word to use. Hofker uses the word "Trimorphism" to express three modes of reproduction but always tries to find three forms in addition, though a difference of about 5μ, which in some cases he gives to differentiate the two extremes of the megalospheric forms, does not seem very satisfactory. In describing *Eponides* [*Pulvinulina*] *repandus* (5), p. 87, he instances, as his two extremes, one megalospheric form with a *small* proloculum (25μ) and another megalospheric form with a *very large* initial chamber ($\pm 32\mu$). This may appear noticeable when magnified 870×, but the worker in Economics cannot consider these forms distinctive if they have to be magnified to such an extent before becoming recognizable.

It is suggested that, in some cases, the only distinction between the two megalospheric forms may lie in the actual mode of reproduction and this can, of course, only be seen in living forms.

It is generally agreed that the microspheric form gives rise asexually to a megalospheric form, and that the megalospheric form gives rise to the microspheric form by the formation and fusion of gametes. There is, however, no reason for asserting that these two methods of reproduction follow immediately on one another, and, under favourable conditions, the megalospheric form reproduces asexually, possibly more than once. In this case we have three modes of reproduction possible, and these are :

(1). The B form gives rise asexually to the A1 form.
(2). The A1 form gives rise asexually to the A2 form.
(3). The A2 form gives rise sexually to the B form.

It must be remembered that there may be no visible distinction between the two A forms, thus giving rise to the impression that there is only Dimorphism present.

Hofker also states (11), p. 1: " . . . In a sample one may thus distinguish the two megalospheric kinds of gamonts, all intermediate stages between these two extremes, and the microspheric agamonts." In the case of *L. peruviana* and *L. R. Douvillei* we also find a range between the two extremes. From a total of seventy-seven sections, sixty-two show a range varying from 204–315μ as the total length of the embryonic apparatus, ten show a range from 278–390μ and five show a range from 350–502μ. All other measurements made showed no marked difference, whilst externally the test is usually domed with a flange, this flange being of varying widths, and the surface is more or less papillate.

It is evident that these two forms are synonymous and it becomes possible to eliminate one of the names. By the rules of priority the name should stand as *Lepidocyclina R. Douvillei* Lisson, but by Article 2 of the International Rules of Nomenclature the name cannot be upheld, since it could be understood to mean that the form is a sub-species of *Lepidocyclina R.* The name should read either *L. robertdouvillei* or *L. douvillei*, the latter being, however, preoccupied by Yabe and Hanzawa in 1922. Since the name *Lepidocyclina peruviana* was put up only a few months later than Lisson's name, and, moreover, is the name given to the more common form, it is suggested that this should be kept as the species name and that the name *L. R. Douvillei* be discarded.

BIBLIOGRAPHY.

(1) TODD and WRIGHT-BARKER. "Tertiary Orbitoids from North-Western Peru," GEOL. MAG., LXIX, 1932, 529 et seq.

(2) T. WAYLAND VAUGHAN. "American and European Tertiary Larger Foraminifera," *Bull. Geol. Soc. Amer.*, xxxv, 1924.

(3) W. L. F. NUTTALL. "Tertiary Foraminifera from the Naparima Region of Trinidad," *Quart. Journ. Geol. Soc.*, lxxxiv, 1928.

(4) N. E. GORTER and I. M. VAN DER VLERK. "Larger Foraminifera from Central Falcon (Venezuela)," *Leidsche Geol. Mededeel.*, iv, Afl. 2, 1932.

(5) J. HOFKER. *The Foraminifera of the Siboga Expedition*, Part 2, 1930.

(6) H. DOUVILLÉ. "Revision des Lépidocyclines," *Mém. Soc. Géol. France*, Nouv. Serie, 1, Mém. 2, 1924.

(7) A. TOBLER. "Neue Funde von obereocänen Grossforaminiferen in der nord-peruanischen Küstenregion," *Eclog. Geol. Helv.*, xx, 1927, 415–422

(8) C. I. LISSON. "Contribution al estudio de algunos foraminiferos terciarios provenientes de la region del Norte del Peru," *Arch. Asoc. Peruana Prog. Ciencia*, 1, Fax. 1, 52–5.

(9) J. J. LISTER. "Contributions to the Life History of the Foraminifera," *Phil. Trans.*, B, clxxxvi, 1895, 401–453.

(10) J. HOFKER. "Une analyse du foraminifère fossile *Orthophragmina advena*, Cushman," *Annales de Protistologie*, iii, Fasc. 4, 1932.

(11) J. HOFKER. *The Foraminifera of the Siboga Expedition*, Part 1, 1927.

The Lower Cretaceous Erratics of the Fraserburgh District, Aberdeenshire.

By George A. Cumming, Ph.D., B.Sc., Carnegie Teaching Fellow, St. Andrews University, and Philip A. Bate, B.Sc., Aberdeen University.

Introduction.

THE fossiliferous boulders of Neocomian age in glacial deposits at Moreseat, in the parish of Cruden, Aberdeenshire, have been known from the middle of last century and have engaged the attention of many workers, but from nowhere else in Aberdeenshire have, until now, Lower Cretaceous rocks been recorded.

The most complete account of the Moreseat rocks is contained in the Report of the British Association for 1897.[1] As these rocks have features in common with the Fraserburgh district rocks to be described it may be well to recapitulate the principal features. The fossils found appear to represent the Speetonensis Zone of the Neocomian and possibly higher zones also. More important in relation to the present paper is the recognition by Jukes Browne of the nature of the Moreseat sandstone. He pointed out that the rock might be termed a gaize, that is, a fine-grained sandstone rich in colloid silica. This is not a common rock and in England is known only as occurring in the Upper Greensand in association with malmstones and sponge beds.

As will be shown, the Fraserburgh district rocks, hitherto unrecorded, form a group of gaizes, malmstones, and sponge beds, although there are differences both in fauna and lithology with the Moreseat rocks.

Some two years ago, Mr. Taylor, of Milton of Philorth, near Fraserburgh, called our attention to some small fossiliferous pebbles he had collected from the surface soil on his farm. These were recognized to be of Cretaceous age, and on investigation it was found that the gravels of the kame area south and south-west of Fraserburgh literally teem with fossiliferous erratics, most, if not all, of Lower Cretaceous age.

There is one reference to these rocks in geological literature. Dr. Bremner, in a paper entitled " Further Problems in the Glacial Geology of North-Eastern Scotland ",[2] states :—

> " In the final stages of retreat, a lobe occupying the basin of the Water of Tyrie separated from the main body of ice in the bed of the Moray Firth. Lines of gravel mounds were deposited along the shrinking margins of the two ice masses in the space between the two : whether we call them kames or glacieluvial deposits or gravel moraines seems immaterial—they are essentially morainic. These gravels are remarkable for the large number of fossiliferous Jurassic erratics they contain."

---

[1] Report of the British Association, 1897, Toronto, 333.

[2] *Trans. Edin. Geol. Soc.*, xii, pt. i, 152.

Dr. Bremner is, however, in error in referring to these erratics as Jurassic.

In collecting material the areal distribution of the erratics was traced. They are restricted to an area north of a line through the villages of New Aberdour and Rathen. None were found east of Rathen. Although the gravel pits in the kame area north of the Water of Tyrie yielded the bulk of our specimens, we found small fragments to be quite numerous in the surface soil near Dundarg Castle and on the farm lands surrounding Milton of Philorth. A few specimens were collected from a gravel pit on the east side of New Aberdour village, but there the erratics are rather rare. The best localities for collecting are the gravel pits at Ford-a-Fowrie and Mains of Cardno. These pits are worked at intervals, and the piles of large boulders thrown aside are the most fruitful sources of material.

Types of Erratics.

The fossiliferous boulders are of various sizes ranging from mere pebbles to boulders measuring 2 feet in diameter. Several distinct types occur. With one exception they have one common property, they contain colloid silica in greater or less amount. It has been found possible to ascertain with some degree of accuracy the horizons from which most of the boulders were derived, and for the others there are reasons for believing that all the erratics belong to the same group of rocks.

Neocomian Boulders.

Upper Hauterivian—Lower Barremian.

The Neocomian erratics seem to be representative of several beds of approximately the same age. It is impossible to differentiate them by means of the fauna, and lithologically they are very closely related. They form a group of malmstones, gaizes, and sponge beds with cherty concretions similar to that found in the Upper Greensand of Hampshire, Surrey, and Berkshire. It is possible to separate the boulders into the following types:—

(A) The most common type of boulder is a blue-grey siliceous rock containing numerous nodules of white chert. Many of the chert nodules are sponge bodies completely filled with silica but showing the spicular mesh. This rock may be described as a sponge chert. It is intensely fossiliferous. Curious anomalies occur in the preservation of the fossils. In most cases calcareous shells have entirely disappeared, leaving beautiful impressions of the ornament and internal casts. In collecting it was often possible to get both the external cover, retaining the shape and impression of the original shell, and also the internal cast. In several of the specimens petrifaction has taken place. The preservation of echinoid spines is curious in this respect. Many Cidarid spines were found, mostly as impressions, the entire organic material having disappeared, but in a few cases perfect replacements of the spine in silica were obtained. A few fossils were found with the original calcareous shell preserved.

The rock shows evidence of having been subjected to great pressure. The white chert nodules are squeezed out into long lenticles, while the larger and more globose fossils are usually squashed and flattened.

A thin section of the rock is interesting. It is almost entirely siliceous apart from grains of glauconite and some limonite in the groundmass. The bulk of the rock is composed of sponge spicules and blebs of colloid silica. The spicular canals nearly all show an infilling of silica, although in one case the infilling material was observed to be glauconite. Many of the spicules have been fractured and recemented, mostly after displacement of the fractured parts. Hinde notes and figures a similar feature in the spicules of the sponge bed in the Lower Greensand of Haslemere.[1] Such fracture and recementation also occurs in one of the petrified Cidarid spines referred to.

(B) This type is common, the boulders being usually of small size. It is a porous rock, light grey in colour on a freshly fractured surface, but showing a brown staining on weathered surfaces. The larger boulders of this rock when found in the gravels have split in many directions, and can only be extracted in small fragments. Ammonite (*Hoplocrioceras*) fragments are the most common fossils.

A thin section shows numerous sponge spicules in a matrix of colloid silica. Scattered grains of brown glauconite occur, and this mineral is also present as an infilling of many spicular canals. Apart from the white chert nodules (type A) this rock is the most siliceous of all types examined. One average specimen, on analysis, yielded over 90 per cent of silica.

(C) Several boulders of what may be described as a quartzose malmstone were found. It is a grey mottled rock, noticeably more sandy than the preceding types.

In thin section it shows numerous angular quartz grains in addition to sponge spicules, glauconite, and colloid silica. A feature of this type is the presence in the rock of abundant small nodules of limonite of about the size of peas. Possibly connected with this type several larger nodules of limonite measuring up to 2 inches in diameter were found free in the gravels. Some of these were split open, and two yielded impressions of a heteromorphic ammonite. Unfortunately the material was too friable to survive transportation.

(D) Boulders of a white sponge rock are of somewhat rare occurrence. This rock consists almost entirely of detached spicules in a matrix of colloid silica. No glauconite was seen nor any fossils apart from the spicules. These, however, are of the same species as those found in the preceding types.

(E) Very decomposed boulders are common, mostly of small size.

---

[1] *Phil. Trans. Roy. Soc.*, clxxvi, pt. ii, 403.

These consist almost entirely of felted masses of sponge spicules. Many are so friable that they fall apart on handling.

Palaeontology.

These boulders have yielded a rich and varied fauna. The fact that most of the identifications had to be made from casts and impressions, excellent though they are, rendered the task somewhat difficult. Several of the forms seem to be new species, or at least new to British Cretaceous rocks, but in view of the method of preservation we have refrained from creating new species, merely indicating affinities wherever possible.

As the ammonites seemed to furnish the best clue to the horizon represented, the specimens were submitted to Dr. L. F. Spath for identification. These included two complete ammonites and a large number of impressions. Dr. Spath reported that the specimens included fragments of *Craspedodiscus*, numerous Criocerates (probably mostly *Hoplocrioceras*) and *Paracrioceras*. He is of the opinion that they are all from beds of about the same age; Upper Hauterivian—Lowest Barremian, equivalent roughly to the Snettisham Clay of North-West Norfolk. Dr. Spath states :—

> " Since Criocerates are extremely rare in the Snettisham Clay (and in the Tealby Limestone, just below), exact correlation is difficult. The North German Criocerates figured by von Koenen (1902) are in a different preservation, not crushed obligingly like yours, which makes the ribbing appear very sharp. Your specimens do not have the fine ribbing on the inner whorls that characterizes the true *Crioceras* (s.s.) from the Middle Hauterivian, and I should prefer to put them higher, i.e. Upper Hauterivian—Lowest Barremian."

The remainder of the fauna is fairly consistent with this horizon, although there are a number of unusual forms.

Of the Cephalopoda apart from the ammonites, we obtained several impressions of belemnites, one of which may be *Belemnites minimus* Lister, and a single flattened *Nautilus*, too much crushed to identify specifically.

Gasteropods are extremely abundant, but the majority are crushed and specific identification difficult. *Cerithium aculeatum* Forbes is very abundant, as is also *Trochus pulcherrimus* Phil. and *Pleurotomaria* sp. Several species of *Emarginula* occur, including *Emarginula neocomiensis* d'Orb. and *Emarginula puncturella* Gardner.

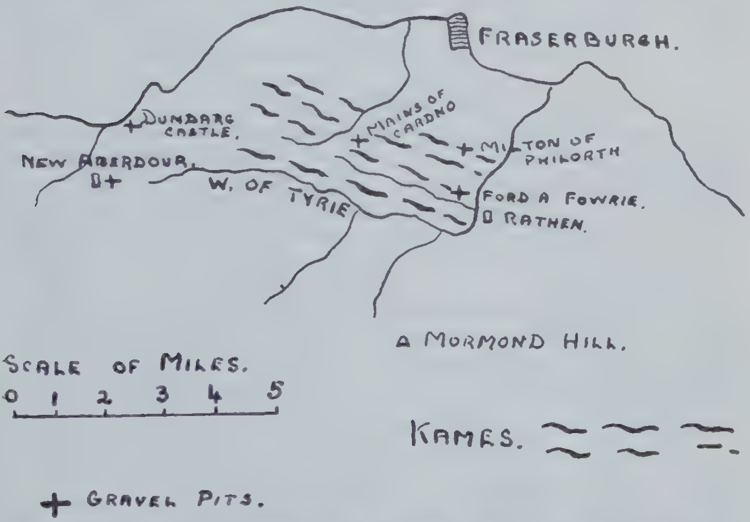
Lamellibranchs are perhaps the most abundant of the larger fossils. In many cases the average size of the shell is less than the normal for the English Neocomian rocks, possibly a dwarfing due to the excess of silica in the sea water. Conditions so favourable for the growth of siliceous sponges were probably somewhat adverse for other forms of marine life.

Of forms found at about a corresponding horizon in England, *Grammatodon securis* (Leymerie), *Lima longa* Römer, *Yoldia scapha* (d'Orbigny), *Cyprina* sp., *Unicardium claxbiense* Woods, *Pecten orbicularis* J. Sowerby, and *Lima parallela* J. de C. Sowerby occur.

A number of forms are new to the Neocomian of Britain. These include *Lima globosa* J. de C. Sowerby (Gault to Cenomanian in England), *Lima* aff. *canalifera* Goldfuss, *Myoconcha* sp., and *Pecten* sp. (a form resembling in ornament the Jurassic species *Pecten clathratus* Römer).

Brachiopoda are very common. *Terebratulina martiniana* d'Orb. is probably the most commonly occurring species. Terebratulids are numerous, but they are almost invariably crushed and flattened. Several species seem to be represented, including one very large species, but *Terebratula depressa* (Lamarck) is the only one we could identify with certainty.

A single specimen of *Orbiculoidea* sp. in the form of a cast was found. This genus is very rare in British Lower Cretaceous rocks, and indeed the only occurrence we could trace is Judd's record of *Discina* sp. nov. from the Upper Neocomian of Speeton.[1]



The Kame Area near Fraserburgh, showing localities where fossiliferous erratics were collected. (After Bremner.)

Fragmentary echinoderm remains are common. Curiously enough these are all spines and detached plates of several species of *Cidaris*. No trace of irregular echinoids was found, although these are common in the Moreseat rocks. As we have pointed out more fully in our note on the Echinoidea, nearly all the Cidarids belong to species occurring in the Upper Cretaceous of England.

---

[1] *Q.J.G.S.*, xxiv, 228.

Small corals are numerous, always in the form of casts. Dr. H. Dighton Thomas examined several of these and reports that none of them are specifically determinable, and only one generically so. It is a *Parasmilia*, a species with a large columella. Several other specimens of this form were found at a later date. Another form, of which only the external mould was obtained, is a trochoid coral, and suggests a genus like *Trochocyathus*.

The sponge remains include several species found in the Lower Greensand—*Geodites wrightii* Hinde, *Geodites pusillus* Hinde, and *Geodites audax* Hinde. Several lithistid sponges almost wholly replaced by chert have been referred to *Doryderma* sp. We can find no record of this genus in the Lower Cretaceous. Zittel gives the range as Upper Cretaceous, although Hinde records it from the Carboniferous.

Foraminifera are rare, but several forms were observed and some isolated (from the small decomposed pebbles of type E). The tests where preserved are perfect replacements in silica, but most commonly the organism is represented by an internal cast in silica.

Complete Faunal List.

Amoniscus tenuis Brady.
Texturariella sp. Cushman = *Textularia turris* d'Orb.
Textularia sp.
Lenticulina sp. Cushman = *Cristellaria rotulata* Lamarck.
Dentalina sp.
Rotalia sp.
Geodites wrightii Hinde.
Geodites pusillus Hinde.
Geodites audax Hinde.
Geodites praelongus Hinde.
Geodites haldonensis Hinde.
Doryderma sp.
Hallirhoa sp. ?
Parasmilia sp.
Trochoid coral.
Serpula. (Several species.)
Cidaris dissimilis Forbes. (Spines and plates.)
Cidaris sp. (Spine like *Cidaris serrifera* Forbes.)
Cidaris sp. (Spine, *Brit. Echinodermata*, i, pl. xii, fig. 8.)
Cidaris vesiculosa Goldfuss. (Spines and plates.)
Cidaris sp. (Club-shaped spine.)
Crania sp.
Orbiculoidea sp.
Terebratulina martiniana d'Orb.
Terebratula depressa (Lamarck).
Terebratula sella ? (Sow.).
Terebratula sp. (Large species.)
Grammatodon securis (Leymerie).
Pectunculus sp.
Limopsis albensis ? Woods.
Pecten striato-punctatus Römer.
Pecten orbicularis J. Sowerby.
Pecten cf. *cottaldinus* d'Orbigny.
Pecten near *aequicostatus* Lamarck.
Pecten sp. (Like *P. clathratus* Römer.)
Plicatula sp.
Lima parallela J. de C. Sowerby.
Lima longa Römer.
Lima globosa J. de C. Sowerby.
Lima aff. *canalifera* Goldfuss.
Astarte elongata ? d'Orbigny.
Astarte subcostata d'Orbigny. (*Venus striato-costata* Forbes.)
Cyprina sp. (Figured by Woods from Speeton, D 1.)
Cyprina sp.
Inoceramus sp.
Myoconcha sp.
Perna sp. ?
Cardita sp.
Exogyra sp.
Nuculana scapha (d'Orbigny).
Nucula meyeri Gardner.
Nucula cornueliana ? d'Orbigny.
Nucula sp.
Unicardium claxbiense ? Woods.
Emarginula neocomiensis d'Orb.
Emarginula puncturella Gardner.
Emarginula sp.
Aff. *Pileopsis neocomiensis* Gardner.
Turritella sp.
Cerithium aculeatum Forbes.
Pleurotomaria sp.
Trochus pulcherrimus Phil.

Trochus sp.
Dimorphosoma sp. ? (Wing broken off.)
Rostellaria sp. ?
Dentalium sp.
Nautilus sp.
Craspedodiscus sp.
Hoplocrioceras sp.
Paracrioceras sp.
Belemnites minimus ? Lister.
Belemnites sp.
Bairdia cf. *subdeltoidea* Münst.

NOTES ON SOME OF THE FOSSILS.

Foraminifera.

When other calcareous organisms show such an advanced degree of alteration as in the Fraserburgh rocks, it might be expected that such delicate bodies as Foraminifera would not survive, but this is not always the case. Even in the sponge chert (type A) foraminiferal remains have been observed, while in the loose textured nodules of type E it has been possible to remove and mount individual specimens.

Examination of the material has led to the recognition of two distinct classes of preservation. In the first, which is confined to the less resistant and consequently less common nodules of type E, the organism appears normal. The chambers are empty, the walls are translucent, and external detail is well shown. In only one respect is there any departure from the normal—the entire specimen is composed of silica.

In the second class an internal cast in silica is found, accurately reproducing the shape and internal detail of the loculi. The examples of this kind taken from the cherty boulders of type A are found lying in their corresponding external moulds. The fact that the majority of the specimens collected belong to the second class has made identification a matter of extreme difficulty. In many of the specimens the passages connecting the loculi, originally extremely minute, are represented by the merest thread of silica. Consequently it is the exception rather than the rule to find an organism replaced by a single complete cast. In general the fossil is found to be made up of a series of detached though more or less interlocking segments, each of which represents one chamber, and great care in handling is necessary if their relationship is not to be disturbed.

In identification the classification evolved by Cushman, and published by him in 1927,[1] has been adhered to as far as possible.

Porifera.

The spongarian remains consist of complete sponge bodies and of detached spicules. The small nodules of type E furnished the most and the best of the sponge material. These nodules are so friable that individual spicules are easily removed without damage.

The siliceous sponges, which are most abundant in the boulders, are almost entirely replaced by chert and their structure is, in the majority of cases, obliterated. In a few examples the secondary silica has not completely invaded the spicular structure, and this can be well seen in thin section.

---

[1] *Contrib. Cushman Lab. Foram. Res.*, iii, pt. i, 1927.

Only four specimens have so far been found which show any semblance of their original external form. Two of these have been assigned to the genus *Doryderma* on account of the disposition of their canal systems. A third is doubtfully referred to *Hallirhoa* sp.

A large number of simple spicules collected probably belong to monactinellid sponges, but none have been specifically determined.

Many spicules belonging to tetractinellid sponges were identified. Outstanding among these are the moniliform acuate spicules of *Geodites wrightii* Hinde, with either simple or trifurcate heads. The head rays of these specimens are themselves often trifid or bifid in one plane. Thin sections of all the Neocomian rock types show these spicules, usually with an infilling of silica in the canals and of an extremely large size. Perfect examples as long as 2·48 mm. have been recovered, as well as fragments of much larger individuals. Occasionally sections are found in which the spicules are entirely dissolved away, leaving only the internal cast of the canal.

Hinde states : " Acuate moniliform spicules rarely occur in the same bed as the trifid forms."[1] In the Fraserburgh material, however, both forms are equally abundant in the same nodule.

A form of spicule nearly as abundant as the last has been referred to *Geodites pusillus* Hinde. This has a straight trifid shaft with a marked constriction immediately below the sharp, conical head rays. In some of our individuals the constricted neck occupies as much as one sixth of the total length.

Geodites praelongus Hinde, *Geodites audax* Hinde, and *Geodites haldonensis* Hinde are also represented in our material.

A few free hexactinellid spicules with long slender rays were isolated from the material, but so far they have not been identified. Two fragments of skeletal mesh were also obtained. These have solid nodes, but otherwise show no characteristic features.

Echinoidea.

Echinoid remains are comparatively abundant. They consist entirely of spines and detached plates of *Cidaris*. No single trace of irregular forms was seen, although these are abundant in the Moreseat rocks. The plates and most of the spines are in the form of impressions or moulds, but these, especially the plates, are absolutely perfect in their reproduction of detail. Several of the spines are petrifactions in silica.

At least five species of *Cidaris* are represented. There is a close correspondence between the types and those figured and described by Wright from the Red Chalk and Speeton. (*Brit. Echinodermata*, i, 79.)

---

[1] *Phil. Trans. Roy. Soc. Lond.*, 1885, clxxvi, 403.

Wright divides the spines into three classes :—

(*a*) Slender, having few (ten to sixteen) longitudinal ridges with a prickly border.

(*b*) Thick, having numerous longitudinal ridges with the prickles almost obliterated.

(*c*) Slender, without ridges, but with an occasional projecting prickle.

A single spine fits into class (*a*). It does not agree with either of Wright's figures, but closely resembles a spine of *Cidaris serrifera* Forbes.

Of class (*b*) there are several spines. Wright states of the Red Chalk spines that they resemble those of *Cidaris dissimilis* Forb. Spines and plates in our possession are indistinguishable from those of *Cidaris dissimilis* Forb. and have been referred to that species.

To class (*c*) belongs a portion of a spine which is practically a replica of Wright's figure (ibid., pl. xii, fig. 8). Of this spine Wright notes :—

> "It is a very peculiar spine, totally distinct from all those of the Cretaceous species."

It is found both in the Red Chalk and at Speeton, but is very rare.

In addition there are two other types present, spines and plates which have been referred to *Cidaris vesiculosa* Goldfuss., and a single club-shaped spine similar to one figured by Wright as a rare form of *Cidaris clavigera* König. (ibid., 73, No. 3).

Lamellibranchiata.

Myoconcha sp.—We have three specimens of a beautiful small shell which we have referred to this genus. Each specimen comprises an internal cast and the cover showing an impression of the ornament.

Description. — Shell oblong, gradually increasing in height posteriorly. Ventral border nearly straight, dorsal rounded. Anterior end somewhat sharp, posterior end rounded.

Ornamentation consists of four equidistant, slightly curving, radial ribs. The radial ribs are crossed by numerous, sharp, concentric ribs which are parallel to the growth lines.

Measurements.	*Length.*	*Height.*	
1	8 mm.	4 mm.	
2	9 mm.	4 mm.	(Approximate.)
3	10 mm.	4·5 mm.	

Affinities.—Quenstedt's figure of *Modiola textilis* from the Krebsscherenkalk (Lower Portlandian) of Germany closely resembles our specimens.[1] We have not been able to trace any similar Cretaceous species.

In ornament this form suggests a young stage of *Myoconcha cretacea* A. d'Orbigny, but the smaller and constant number of radial ribs and the uniformity in size of the specimens would seem to indicate that this is a separate species.

---

[1] Quenstedt, *Der Jura*, Tab. 98 and p. 795.

Pectunculus sp.—Several specimens were obtained of a small *Pectunculus.* Unfortunately they are all internal casts and the ornament is lost. The hinge is well preserved. The shell differs from *Pectunculus marulliensis* Leymerie in having a subquadrate outline and more prominent umbones.

Lima aff. *canalifera* Goldfuss.—A complete right valve and the impression of the greater part of another were found. The shell is very near to *Lima canalifera* Goldfuss. Mr. H. Woods, who has seen the specimens, agrees, but states that differences in preservation prevent him from giving a definite opinion. The English specimens of *Lima canalifera* Goldfuss are from the zone of *Pecten asper.*

Pecten sp.—A beautiful shell of which only a single right valve was found. In size and ornament it closely resembles the Jurassic form *Pecten clathratus* Römer.

Astarte elongata (?) d'Orbigny.—We have somewhat doubtfully referred a single internal cast to this species. It agrees almost perfectly with the internal cast of a right valve figured by Woods (*Cret. Lamell. of England*, ii, pl. xiv, fig. 3).

Astarte subcostata d'Orbigny (*Venus striato-costata* Forbes).—Examples of this small *Astarte* are extremely common. It is also found at Moreseat and a specimen in the Moreseat collection in Marischal College is labelled in Forbes' handwriting "*Venus striato-costata*". Sharman and Newton pointed out that the shell is an *Astarte*, and it is included in their list of Moreseat fossils as *Astarte* (*Venus*) *striato-costata* Forbes (GEOL. MAG., 1896, 251). Examination of several specimens shows an agreement in characters with *Astarte subcostata* d'Orbigny, and they have been referred to that species.

Gasteropoda.

Cerithium aculeatum Forbes.—This species is recorded from Moreseat and its characteristics are very fully described by Sharman and Newton (GEOL. MAG., 1896, 250). We have a number of moulds which agree so closely with this description that we have no hesitation in referring them to the same species.

Trochus sp.—This, although we have not seen the Moreseat specimen, agrees with the description of a *Trochus* found at that locality and also described by Sharman and Newton (GEOL. MAG., 1896, 250). Our specimen is about a third of an inch in length, the sides are flat, and the sutures not depressed, so that it forms an almost complete cone with flattened sides. The ornament is not very well preserved, but the slight ridge at the top and bottom of each whorl can be distinguished.

Ostracoda.

In addition to foraminifera and sponge spicules the small boulders of type E have yielded Ostracod remains. Three specimens were found. Each consists of a perfect siliceous internal cast of both valves. No trace of the original shell remains and only internal details of the valves are available for identification purposes. All three are referred to *Bairdia* cf. *subdeltoidea* Münst.

APTIAN BOULDERS ?

(F) Representatives of a fauna which has a pronounced Aptian appearance were found in boulders which closely resemble type B of the Neocomian boulders and were at first confused with them. There are, however, slight but constant differences which justify us in regarding the rock as representing a different bed.

The rock is light grey, almost white, in colour and rather porous. It weathers with a white surface in contrast to the brown staining of the Neocomian rock. It may be termed a " sponge silt " after the usage of the Geological Survey,[1] for the rock consists of spicules (perfect and broken), colloid silica, with a certain amount of fine quartz sand. Glauconite is found in scattered grains and as an infilling of spicular canals. The rock differs from the Neocomian type in containing a smaller proportion of spicules and a larger proportion of quartz grains, but the relationship is very close.

The fauna includes such Aptian forms as *Barbatia aptensis* (Pictet and Campiche), *Astarte upwarensis* Woods, *Modiola aequalis* J. Sowerby, *Unicardium vectense* Woods, and *Lima* sp. cf. *villerensis* Pictet and Campiche.

Three forms occur which in England are known only from the Upper Cretaceous, *Belemnites minimus* Lister, *Limopsis albensis* Woods, and *Argiope decemcostata* Röm.

Species which are common to this rock and to the Neocomian rocks are *Pectunculus* sp., *Grammatodon securis* Leymerie, *Emarginula puncturella* Gardner, and *Pecten* aff. *striato-punctatus* Römer.

Lithologically, this rock cannot be separated from the group of which the Neocomian rocks form a part, but from the faunal evidence available it must be considered as higher in the series and probably Aptian in age.

FAUNAL LIST.

Sponge spicules.
Cidaris sp. (Spine.)
Kingena lima Defr.
Terebratula sp.
Argiope decemcostata (Röm.).
**Pectunculus* sp.
**Grammatodon securis* (Leymerie).
Barbatia aptensis (Pictet and Campiche).
Unicardium vectense Woods.
Modiola aequalis J. Sowerby.
**Limopsis albensis* Woods.
Lima sp. cf. *villerensis* Pictet and Campiche.
**Pecten orbicularis* J. Sowerby.
**Pecten* aff. *striato-punctatus* Römer.
Plicatula sp.
Astarte upwarensis Woods.
Inoceramus sp.
Emarginula puncturella Gardner.
Dentalium decussatum J. Sowerby.
Belemnites minimus Lister.

* Found in Neocomian boulders also.

---

[1] "Cret. Rocks of Britain," *Mem. Geol. Surv.*, i, 358.

Boulders Whose Age is Uncertain but Probably Cretaceous.

Several fossiliferous boulders were collected of types differing from those just described. No diagnostic fossils have so far been found, so it is impossible to assign a precise age to these rocks, but from lithological and other considerations they probably belong to the same suite of rocks as the others.

(G) The boulders are rather large and are fairly common. The rock is dark grey and weathers with a brown crust. Fossils are somewhat rare and are always in the form of casts and moulds.

In thin section this is a very beautiful rock. Angular quartz grains are abundant. Grains of glauconite, some of large size and of a very vivid green colour, are common. A large proportion of the matrix consists of colloid silica both in the granular and in the globular form. Mica occurs sparingly.

Of organic material the striking feature is the presence of radiolaria of *Nassellaria* type. There are many spicular fragments with glauconite filling the canals. Small fragments of carbonized wood are scattered throughout the matrix.

This rock may be described as a quartzose malmstone with radiolaria.

The larger fossils include the impressions of two belemnites too fragmentary for precise identification. One appears to be a small hastate form, the other is that of a large belemnite. The other fossils include a number of species which may be new. We have been unable to match them. A coarsely ribbed *Astarte* and an ovate *Nucula* are the most common forms. The others are *Lucina* sp. (a coarsely-ribbed species with a markedly produced anterior margin), *Corbis* sp. (?), *Myoconcha* sp., and a single specimen which has been doubtfully referred to *Astarte striata* J. de C. Sowerby.

Faunal List.

Radiolaria.
Sponge spicules.
Astarte sp.
Astarte striata ? J. de C. Sowerby.
Lucina sp.
Nucula sp.
Myoconcha sp.
Corbis sp.
Belemnites sp. (Small hastate form.)
Belemnites sp.

Several boulders were found illustrating a variant of this type. The matrix is crowded with comminuted shells and fragments of carbonized wood. The only entire shell observed was a specimen of the ovate *Nucula*. In thin section the rock closely resembles the above. It is slightly more sandy, but the same radiolarian forms are present.

(H) Boulders of a light brown quartzose malmstone are fairly common. This rock differs from type G in being distinctly more sandy and in being without radiolaria. A thin section, however, shows the presence of colloid silica, glauconite, and a few spicular fragments. Small pieces of carbonized wood are common.

The fossils found were several internal moulds of *Astarte*, the ovate *Nucula* also found in type G, several casts of what may be a minute cup coral, and cycloid fish scales with a deeply imbricated pattern.

(I) Boulders of a light brown sandy shale are of somewhat rare occurrence in the gravels. This rock differs from all the others collected in being without colloid silica, sponge spicules, or glauconite. It has the appearance of an estuarine silt.

The matrix is crowded with fragments of carbonized wood and with cycloid fish scales. Some of the scales seem to be identical with those found in type H. A single somewhat squashed lamellibranch was found. It resembles closely *Cyrena jamesoni* Forbes of the Jurassic Great Estuarine Series, but the probabilities seem to be against it being that species.

An exact determination of the age of these rocks presents many difficulties. The fossils are not at all helpful. Dr. L. R. Cox, of the British Museum of Natural History, who examined some of the specimens, could not determine them precisely, but was of opinion they are more probably Upper Jurassic than Lower Cretaceous. The ovate *Nucula*, which is common, closely resembles *Nucula obtusa* J. de C. Sowerby of the Upper Greensand, but Dr. Cox points out that this is a type likely to occur at any horizon. The coarsely ribbed *Astarte* he regarded as more closely comparable to Jurassic forms than to Cretaceous ones.

Dr. Cox, however, was unacquainted with the lithology of the boulders in our collection, which in this case seems to be a more important factor than the faunal content. If we except boulders of type I, all the others contain glauconite which alone is suggestive of a Cretaceous rather than a Jurassic age, but the most significant feature is that the rocks are malmstones and are found in association with a group of closely-related rocks whose age we can determine, viz. Neocomian. Unfortunately, as most of the sponge spicules in these rocks are broken fragments impossible of extraction from the matrix, they cannot be compared with the entire spicules from the Neocomian rocks. Malmstone and gaize are, however, so rare in occurrence that it would be stretching coincidence to an extreme to find such rocks of both Jurassic and Cretaceous age preserved as erratics in the same glacial gravels. For these reasons, then, we have preferred to regard all these rocks as belonging to a group of malmstones and sponge beds of Upper Neocomian and possibly Aptian age.

The position of boulders of type I is less certain. The lamellibranch found is strongly reminiscent of *Cyrena jamesoni* Forbes, and the rock may possibly be Jurassic. Against this is the fact that the rock is of a soft fragile nature, not at all likely to be the only Jurassic rock to survive transportation by ice. On the other hand, there are two factors which link it with the malmstones, the evidence of the fish-scales and the presence of carbonized wood.

THE MORESEAT GREENSAND.

We have had the opportunity of examining the collection of Moreseat specimens in the Geological Museum, Marischal College, Aberdeen. The rock is quite unlike any of our types. In the hand it is appreciably more sandy than any of the Fraserburgh rocks. In thin section it is seen to contain a greater proportion of quartz grains and of mica, while the glauconite is more uniformly distributed throughout the rock. The Fraserburgh rocks contain a greater proportion of sponge spicules and of colloid silica. No chert is found at Moreseat.

Of the Moreseat fauna several species occur in the Fraserburgh rocks. These are *Trochus pulcherrimus* Phil., *Trochus* sp., *Cerithium aculeatum* Forbes, *Grammatodon securis* (Leymerie), and *Astarte subcostata* d'Orbigny.[1] A noteworthy difference in the faunas is the occurrence of only irregular echinoids at Moreseat and of only regular forms at Fraserburgh.

NOTE ON THE CHEMICAL COMPOSITION OF SOME OF THE MATRICES.

A series of chemical analyses of several of the types was carried out. These show the intensely siliceous nature of the rocks.

In the case of types A and B a straightforward chemical analysis was performed, but with type G a different procedure was adopted. It was desired to estimate the glauconite content, and as limonite was also present it was impossible to use the total percentage of Fe as a basis from which to estimate the amount of the former mineral. This was therefore calculated in thin section by the Rosiwal method.

(1) A characteristic sample of type A. The portion for analysis was selected free from nodules of chert and macroscopic fossils.

Total SiO_2 (corrected by HF and H_2SO_4)	76·53%
Fe	4·86%
Ca	Traces
Mg	,,

(2) Type B. Silica only estimated.

Total SiO_2	92·0%

(3) Type G. Quartzose malmstone with radiolaria.

(*a*)	Total SiO_2	83·20%
	Glauconite (estimated by Rosiwal method)	8·17%
(*b*)	Total SiO_2	82·54%
	Glauconite	8·30%

LITHOLOGY AND CONDITIONS OF DEPOSITION OF THE ROCKS.

The lithology of this group of malmstones and sponge beds offers some very curious and interesting features.

The types A, B, C, D, E, F, and the Moreseat rock resemble closely in their minute character the sponge beds and malmstones of the Upper Greensand of Surrey, Hampshire, and Berkshire described by Hinde[1] and by Jukes-Browne and Hill.[2]

---

[1] See note on *Astarte subcostata* d'Orbigny.

As in the more siliceous malmstones, while spicules and fragments of spicules are abundant the porosity of the rock is due to the many hollow cavities or casts of spicules which interpenetrate it. The spicules as in the English rocks consist of amorphous, not crystalline or chalcedonic silica, and as in these rocks the spicular canals are always filled with glauconite or chalcedonic silica, these canal casts often remaining in the spaces from which the spicules themselves have been removed.

Types G and H differ from the more siliceous malmstones in the greater amount of inorganic terrigenous material they contain, in the presence of radiolaria, and notably in the frequent occurrence of wood fragments. The amount of colloid silica is appreciably less and the spicules are almost entirely fragmentary.

Type I is not a malmstone but is entirely an estuarine rock.

Jukes-Browne, in the report on the Moreseat fossils states[3] :—

> "The formation of gaize and malmstone probably took place in clear water of a moderate depth; it is not a shallow water deposit and yet it was deposited within range of a current which carried fine sand."

This conclusion would be entirely acceptable in the present case were it not for the presence of boulders of types G, H, and I.

Type I, as stated, is of estuarine character, while types G and H, although malmstones, must have been formed near an estuary, certainly within range of a current carrying much fine sand and land material in the form of drift vegetation.

Twenhofel, in the *Treatise on Sedimentation*, states[4] :—

> "The Upper Greensand in the Isle of Wight has several beds containing sponge spicules. Some cherts occur in them. These beds also contain glauconite and quartz grains. The chert has the characteristics of a chemically deposited bed which includes the sponges, glauconite, and sand. This deposit might have been due to rapid precipitation near the mouth of a river where the fresh and salt water met. The high silica content made conditions favourable for the growth of siliceous sponges."

This suggestion seems of great interest in the present case. If we assume the more siliceous malmstones, chert, and sponge beds to be formed as Twenhofel has suggested for the Upper Greensand chert, then a feasible explanation of types G and H presents itself.

The zone where fresh and salt water meet is subject to tidal fluctuation: the greatest precipitation would take place at or below the low tide limit; here probably the conditions would most favour the growth of siliceous sponges and the more siliceous rocks would be formed. In the tidal zone precipitation would be less, but the silica content would still be high and furnish conditions suitable for radiolaria but perhaps not suitable for siliceous sponges. The amount of terrigenous material would be appreciably greater than in the more siliceous rocks, while spicules and fragments of spicules from the favourable zone seaward would be drifted in by the tides.

---

[1] *Phil. Trans. Roy. Soc.*, clxxvi, pt. ii, 1885, 403.

[2] "Cret. Rocks of Britain": *Mem. Geol. Surv.*, i, 352.

[3] *B.A. Report, Toronto*, 1897, 338.

[4] Loc. cit., 450.

The indications point to types G and H having been formed in some such manner as this. The wood fragments and numerous quartz grains indicate the presence of a river current, the colloid silica and the radiolaria show that the silica content of the water was high, while the broken nature of the spicules suggests that they have drifted to their present position.

CONCLUSIONS.

It is generally assumed that the Lower Cretaceous boulders which have been previously described from counties bordering the Moray Firth have been derived from the floor of that estuary and afford an interesting clue to the nature of the rocks which follow the Jurassic deposits of Ross and Sutherland. In the present case the evidence is clear. Dr. Bremner's glacial studies have shown that the ice which deposited the gravel mounds was a lobe from the main mass out in the Moray Firth, thus pointing definitely to the place of origin of the boulders and affording a further clue to the nature of the rocks which underlie the Moray Firth.

The early workers on the Moreseat rocks encountered difficulties in their interpretation, the fauna containing representatives of Upper Cretaceous species as well as Lower Cretaceous, while all the boulders were so similar in lithology as to indicate one bed. Sharman and Newton, indeed, suggested that in Aberdeenshire the distinct horizons of Lower Greensand, Gault, and Upper Greensand are incorporated in one bed of nearly uniform character.[1] Jukes-Browne, however, showed that the fauna is a Lower Cretaceous one with a slight admixture of species which in England are confined to the Upper Cretaceous.[2]

Practically the same difficulties are encountered with the Fraserburgh rocks. Lithologically, the rocks are very similar, but there is a greater variety than at Moreseat and it is possible to distinguish several beds. The palaeontological evidence is, however, just as confusing. There is a similar mixture of Lower and Upper Cretaceous forms along with others not found elsewhere.

With boulders of types A, B, C, D, and E the occurrence of the ammonites *Hoplocrioceras*, *Paracrioceras*, and *Craspedodiscus* enables us to fix the age with some certainty as Upper Hauterivian—Lowest Barremian. A large proportion of the other forms are in accordance with such an interpretation, but some of the most commonly occurring forms, as *Lima globosa* J. de C. Sow. and some of the species of *Cidaris*, are not known in England below the Gault.

[1] GEOL. MAG., 1896, 254.
[2] *B.A. Report, Toronto*, 1897, 337.

The boulders of type F to which we have doubtfully assigned an Aptian age show the same admixture of forms. Aptian species predominate, but there are several forms common to this and to the Neocomian rocks. In the absence of any ammonites it is impossible to fix a precise horizon, and with the knowledge that in the Neocomian rocks higher forms do occur it may be that this rock is also Neocomian in age.

With the remaining types, G, H, and I, the palaeontological evidence is still more unsatisfactory and we are forced to rely mainly on lithological affinities in assigning a probable age. There is an almost complete absence of forms which can be identified specifically. We have indicated previously our reasons for including these types with the Neocomian and possibly Aptian rocks in the same group of malmstones and sponge beds.

On lithological grounds, it is impossible to separate the Moreseat rocks from this group, but as representing the Speetonensis Zone they are probably older than any of the Fraserburgh rocks.

To sum up, the Lower Cretaceous erratics of Aberdeenshire, probably representing rocks *in situ* on the floor of the Moray Firth, include a group of malmstones and sponge beds similar to that found in the Upper Greensand of England. There are indications that this group of rocks was deposited near an estuary.

The age limits of this malmstone group are uncertain. The oldest rocks definitely identified are the Moreseat boulders which indicate the Speetonensis Zone (Middle Hauterivian). The Fraserburgh rocks are representative of several beds, include some of Upper Hauterivian—Lowest Barremian age, and others which may be Aptian, equivalent roughly to the Lower Greensand of England. Any more precise determination is impossible at present.

ACKNOWLEDGMENTS.

We wish to express our grateful acknowledgments to Dr. L. F. Spath for his determination of the ammonites ; to Mr. H. Woods, Dr. H. Dighton Thomas, and Mr. L. R. Cox for notes on several of the fossils, and especially to Dr. John Pringle, of H.M. Geological Survey, for advice and criticism willingly given on many occasions. We are also indebted to thè Carnegie Trust for a monetary grant, which helped to defray the cost of this work.

A Tholeiite Dyke near Buxton, Derbyshire.

By F. Wolverson Cope, M.Sc., Bedford College, London.

I. Preliminary Remarks.
II. Description of the Dyke.
III. Petrography of the Tholeiite.
IV. Geological Age of the Intrusion.
V. Description of the Xenoliths.
VI. Source of the Xenoliths.

I. Preliminary Remarks.

The dyke which is to be described is of interest for two reasons: first, because a dyke actually cutting the limestones of Derbyshire has never been recorded, and secondly on account of the xenoliths which it contains.

Associated with the Carboniferous rocks of Derbyshire are lava flows, tuffs, sills, and volcanic necks, but intrusive bodies in the form of dykes are very rarely seen. Sir Archibald Geikie mentioned the existence of two small dykes of dolerite which traverse one of the Grangemill Vents at Grangemill, about 5 miles to the west of Matlock Bath (1),[1] and Arnold-Bemrose, in the discussion which followed the reading of his paper on the Toadstones of Derbyshire, stated that "the few dykes observed in Derbyshire were found in the agglomerates of the Grangemill and Hopton Vents and in the upper lava near Priestcliffe" (2).

II. Description of the Dyke.

The dyke is to be seen at Buxton Bridge, about 2½ miles to the north-east of Buxton, where the road from that town to the village of Hargatewall crosses Great Rocks Dale (Ordnance Survey: Six-inch, Derbyshire, Sheet XV, S.W.). A few yards to the east of the bridge over the railway, a northerly-running road-cutting gives access to a limestone quarry, and the dyke is well exposed about 200 feet to the north of the cutting entrance in the roughly vertical walls, which are about 15 feet in height (Fig. 1). It is vertical, about 12 feet in width, and follows one of the major-joint directions of the limestones into which it is intruded, thus striking in a west-north-west direction. The tholeiite composing the dyke shows a rough spheroidal weathering in the central part, but at the contacts with the limestone it is decomposed to a considerable extent. Close to the contacts, weathered masses of the igneous rock have yielded a number of xenoliths of sedimentary rocks which are described in Section V of this paper. The beds which are cut through by the dyke at this point are the thickly-bedded light grey fine-grained limestones of the Chee Tor Rock (3) at an horizon about 80 feet below the Lower Lava Flow of the area. The beds dip towards the north at an angle of about 15°. At the contacts with the tholeiite, the limestone is marmorized, and a saccharoidal appearance accompanied by numerous small rusty-looking spots persists to a distance of about 6 inches from each contact.

---

[1] Numbers in parentheses refer to the list of references at the end of the paper.

III. PETROGRAPHY OF THE THOLEIITE.

A. MACROSCOPIC.

In hand specimen the fresh tholeiite is a bluish-black fine-grained rock. Small insets of plagioclase are usually to be seen, but certain very fine-grained areas of restricted extent are practically devoid of these and, as a result, the rock presents rather a patchy appearance to the naked eye. It has a specific gravity of 2·76.

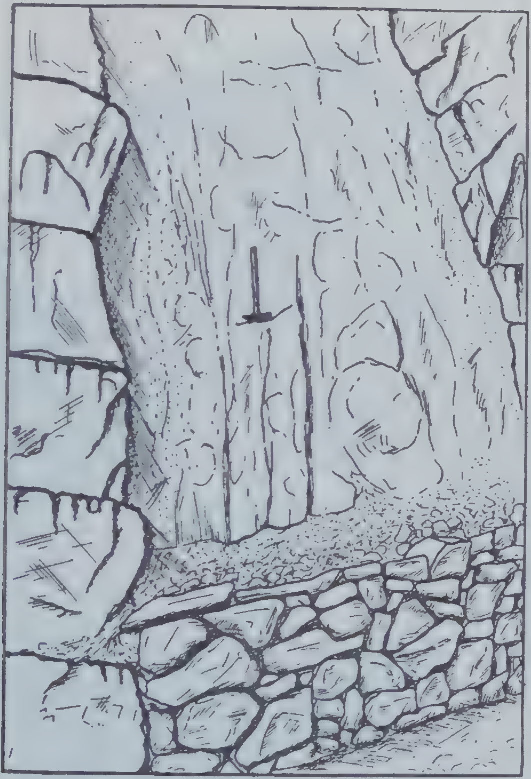


FIG. 1.—Tholeiite Dyke cutting Chee Tor Rock, Buxton Bridge, Derbyshire. (*From a photograph.*)

B. MICROSCOPIC.

(a) *Texture.*

The rock, which consists largely of augite and plagioclase, exhibits a sub-ophitic granular texture; the augite and plagioclase form crystal aggregates separated from one another by a glassy mesostasis with iron ore and a chloritic mineral (Fig. 2, A).

(b) *Mineral Composition.*

(i) Augite occurs in small anhedral grains, colourless and non-pleochroic, the majority having a mean diameter of about 0·2 mm., but occasional grains having a diameter of 0·5 mm.

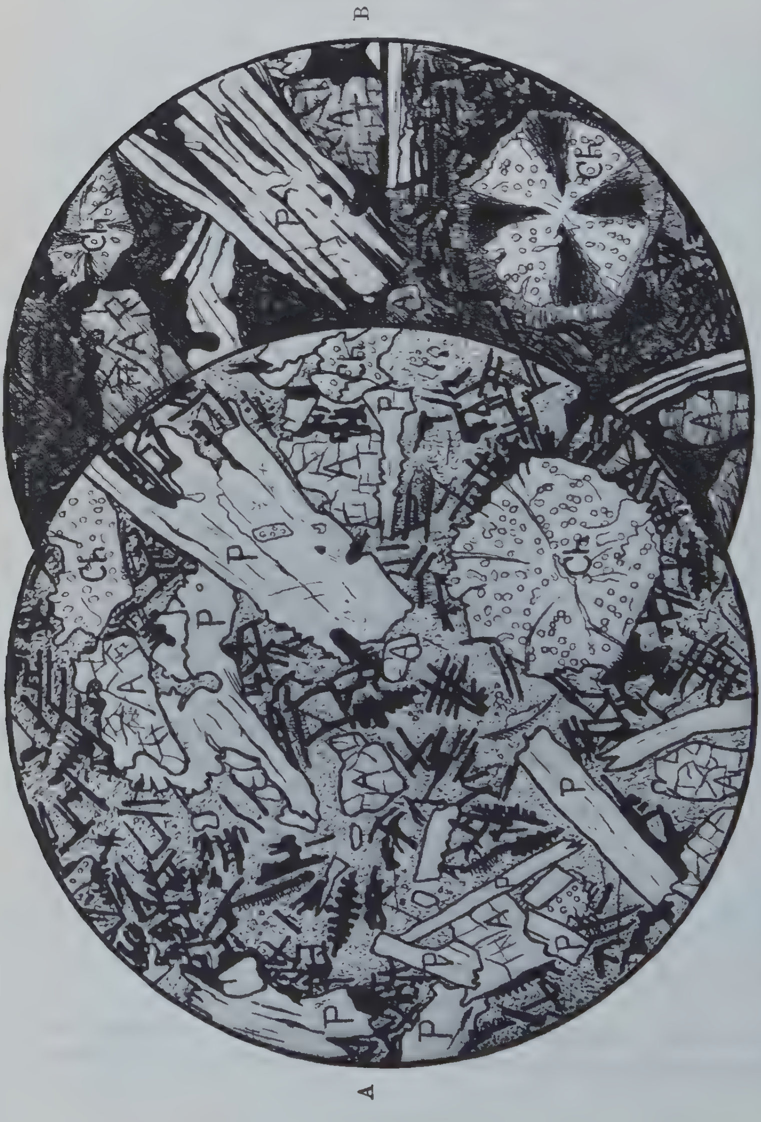


FIG. 2.—MICROGRAPHS OF THOLEIITE FROM CENTRE OF DYKE AT BUXTON BRIDGE, DERBYSHIRE.

A. Ordinary Light. B. Crossed nicols. A = augite; Ch = chloritic mineral; P = plagioclase. The black areas in A are skeletal crystals of ilmenite. Diameter of field = ¾ mm. Directions of vibration of nicols are N.-S. and E.-W.

(ii) Plagioclase is present in the form of laths up to about 2·5 mm. in length. They show zoning in a number of cases, the centre corresponding to the composition $Ab_{45}An_{55}$, and thus approximating to labradorite, the marginal zone being richer in albite and corresponding to the composition $Ab_{66}An_{34}$, a fairly acid andesine.

(iii) The iron-ore forms a heavy felt of skeletal crystals within the mesostasis. The form of the crystals and the high percentage of titanium dioxide shown in the analysis of the next section suggest that this iron-ore is largely ilmenite.

(iv) The chloritic mineral is greenish yellow in ordinary light, and is non-pleochroic. It is usually very irregular in shape, but occasionally shows a six- or eight-sided outline as though a pseudomorph after another mineral. It is crossed by irregular cracks, sometimes encloses minute crystals of calcite, and is seen to be crowded with numerous "bacteria-like" bodies; these are usually round, with a diameter of about 0·008 mm., but sometimes they are more elliptical with the longer axis about 0·013 mm. and the shorter axis about 0·007 mm. Under crossed-nicols the chloritic mineral is seen to be surrounded by a rim of radiating fibres of "chlorite" which are invaded to some extent by the finer rods of skeletal ilmenite. The chloritic mineral extinguishes in sectors, the "bacterialike" bodies extinguishing with the enveloping mass. The mineral exhibits second order polarization colours, although these are largely masked by the absorption colour, and has birefringence moderate, $\gamma - \alpha =$ circa 0·009. The mean refractive index (determined by the method of immersion) $= 1{\cdot}573$. The enclosed bodies show no structure under a high-power objective, and so differ from those described by Tomkeieff in a chlorite from a basaltic lava at Knot Low in Derbyshire (4). The bodies in the chloritic mineral of the tholeiite are also very much smaller and more rounded than the ones described in the paper cited. Campbell and Lunn have described an isotropic chlorophaeite from the tholeiites of Dalmahoy and Kaimes Hills, Edinburgh (5), where much of the microscopic chlorophaeite is found as a pseudomorph after olivine and "not infrequently the mineral is crowded with minute tubular bodies simulating micro-organisms".

C. CHEMICAL COMPOSITION.

Upon analysis, a typical sample of the tholeiite gave the chemical composition shown in Table I.

The high carbon dioxide percentage appears to be due to the presence of small crystals of calcite within the areas of the chloritic mineral, whilst the high proportion of ores is reflected in the high percentage of titanium dioxide and of ferric oxide.

In mineral constitution, chemical composition, and texture, the dyke rock is a tholeiite having affinities with tholeiites of the Brunton type.

IV. GEOLOGICAL AGE OF THE INTRUSION.

Only tentative suggestions of the age can be made. Field relations demonstrate that the intrusion is post-D_1 only. Although the local trend of the dyke appears to be west-north-west, the general trend cannot be determined owing to lack of exposures.

TABLE I.

CHEMICAL ANALYSIS OF THE BUXTON BRIDGE DYKE.

(Analysed by W. A. Deer.)

	Per-centages.	*Molecular Pro-portions.*
SiO_2	49·04	·817
Al_2O_3	11·86	·1165
Fe_2O_3	4·31	·027
FeO	7·81	·108
MgO	5·60	·140
CaO	11·37	·203
Na_2O	2·19	·035
K_2O	0·40	·004
H_2O (+ 110° C.)	2·24	—
H_2O (– 110° C.)		
CO_2	1·16	·0263
TiO_2	3·75	·0468
P_2O_5	0·26	·0015
MnO	0·24	·0033
BaO	trace	—
	100·23	

Norm.			
Quartz			9·57
Orthoclase			2·22
Albite			18·34
Anorthite			21·54
Diopside	$CaSiO_3$	10·96	21·05
	$MgSiO_3$	7·45	
	$FeSiO_3$	2·64	
Hyper-sthene	$MgSiO_3$	6·50	8·35
	$FeSiO_3$	1·85	
Magnetite			6·26
Ilmenite			7·14
Apatite			0·50
Calcite			2·63
			97·60
Water			2·24
			99·84

Alongside the analysis of the Derbyshire tholeiite in Table II are drawn up a number of comparable analyses of rocks of Permo-Carboniferous and of Tertiary age. It is seen that the Derbyshire tholeiite compares fairly well with the tholeiites of the Brunton type (6) from Mull (columns E and F), which are Tertiary in age, but the comparison with a Permo-Carboniferous tholeiite from Central Scotland (column B) described by Walker (7) and with the Elsdon Dyke (column C) and Binfield Dyke (column D) of similar age, described by Holmes and Harwood from Northumberland (8, 9), is even closer.

V. DESCRIPTION OF XENOLITHS.

Near the contacts with the country-rock the tholeiite is very largely decomposed, and by breaking up quantities of the friable rock in the dry condition a number of small more resistant blocks were discovered. The majority of these were the kernels of weathered spheroids of the dyke rock, but five have proved to be xenoliths of sedimentary rocks. They were themselves somewhat friable, and hardening was necessary before sections could be prepared. The unexpected interest attached to these xenoliths merits a detailed description of their petrography.

The largest block obtained is sub-angular, about 3 inches long, 2 inches wide, and 1 inch thick. It consists of closely-packed crystals of dolomite and calcite, and is clearly a fragment of dolomitized limestone which has undergone low grade contact metamorphism.

TABLE II.

COMPARATIVE TABLE OF ANALYSES.

	A	B	C	D	E	F
SiO_2 . .	49·04	49·10	49·59	50·07	51·53	51·63
Al_2O_3 . .	11·86	12·13	13·66	14·53	11·05	11·77
Fe_2O_3 . .	4·31	4·61	5·29	1·76	2·73	3·23
FeO . .	7·81	8·92	7·90	8·26	10·98	10·47
MgO . .	5·60	4·50	5·09	6·77	5·21	5·02
CaO . .	11·37	8·20	9·34	11·50	9·68	9·34
Na_2O . .	2·19	2·14	2·27	1·93	3·48	2·90
K_2O . .	0·40	2·10	0·91	0·85	0·86	0·91
H_2O+ .	2·24	2·50	1·51	0·82	1·26	1·40
H_2O-		1·02	1·13	0·52	0·71	0·68
CO_2 . .	1·16	—	0·52	1·61	0·08	0·11
TiO_2 . .	3·75	4·02	2·59	1·14	1·57	2·00
P_2O_5 . .	0·26	0·51	0·10	0·16	0·22	0·29
Cl . . .	—	—	trace	—	—	—
S . . .	—	0·03	0·05	0·08	—	—
FeS_2 . .	—	—	—	—	0·26	0·08
Cr_2O_3 . .	—	—	—	0·02	—	—
V_2O_3 . .	—	—	0·05	0·06	—	—
MnO . .	0·24	0·15	0·25	0·19	0·45	0·35
(Co, Ni)O .	—	—	—	—	—	0·04
SrO . .	—	—	trace	0·02	—	—
BaO . .	trace	—	0·01	0·04	—	0·03
Li_2O . .	—	—	trace	trace	trace	—
	100·23	99·93	100·26	100·30	100·07	100·27

A. Buxton Bridge Dyke, near Buxton, Derbyshire. Tholeiite. Analyst, W. A. Deer.
B. Kinkell Tholeiite (Southern type). Analyst, J. Jakob.
C. Elsdon Dyke, Grasslees Burn, Northumberland. Analyst, H. F. Harwood.
D. Bingfield Dyke, Redhouse Burn, Northumberland. Tholeiite (Brunton type). Analyst, H. F. Harwood.
E. Dyke. Shore, ¼ mile E. of Arla and 5½ miles S.E. of Tobermory, Mull. Tholeiite (Brunton type). Analyst, E. G. Radley.
F. Dyke. Shore, ¼ mile N. of Kintallen and 3 miles N.N.W. of Salen, Mull. Tholeiite (Brunton type). Analyst, E. G. Radley.

The other four xenoliths, the largest of which measures about 2½ inches in length, 1 inch in width, and ¾ inch in thickness, around which the greatest interest centres, are all light brown fine-grained sandstones showing lamination parallel to the largest surfaces. They exhibit the same mineral constitution and texture as each other, and are all to be referred to the same source.

In thin section each of these four xenoliths is seen to consist of quartz, orthoclase, microcline, plagioclase, biotite, and muscovite with some zircon, magnetite, and chlorite. There is very considerable excess of quartz over the felspars. Of the latter, orthoclase for the greater part remarkably fresh and showing cleavage plainly, is the most abundant, whilst microcline and plagioclases which are also fresh are about equal in amount. Of the micas, biotite predominates over muscovite. Zircon and magnetite occur in occasional rounded grains, whilst only very rare wisps of chlorite are to be seen. The mutual relationships of the constituent grains of the rock are peculiar; this may be seen from Fig. 3. The micas exhibit a tendency to follow the lamination planes, the felspar grains are subangular, and the quartz grains are irregular and exhibit the appearance of interlocking with each other. The quartz is seen to conform to the outlines of the felspar grains. There is no evidence of the rock having been thermally metamorphosed. In a number

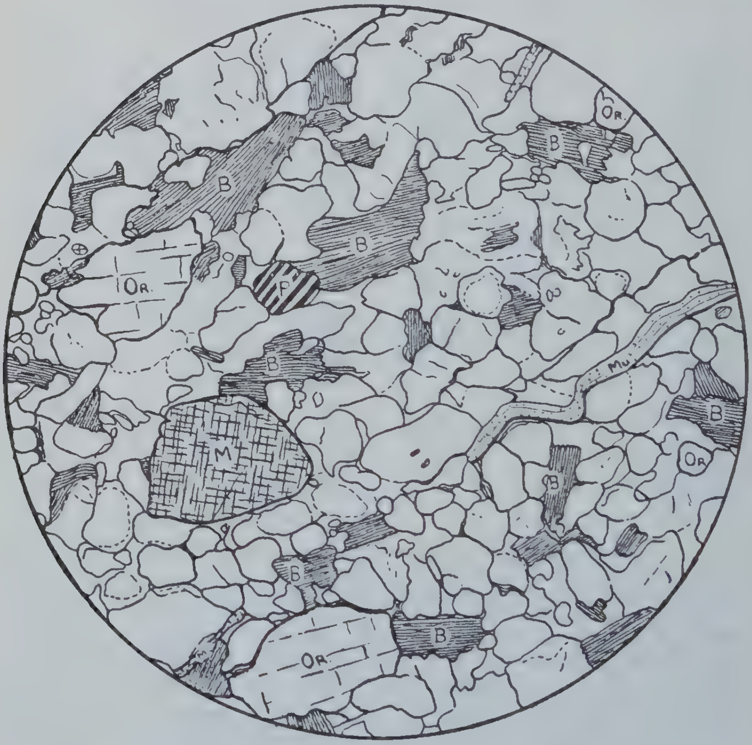


Fig. 3.—Showing relationship of mineral-grains in sedimentary xenolith from tholeiite dyke at Buxton Bridge, near Buxton, Derbyshire. Two lamination planes may be seen running across the field in a N.E.–S.W. direction. Quartz = white; orthoclase = Or.; microcline = M.; plagioclase = P; biotite = B.; muscovite = Mu.; Diameter of field = 2 mm.

of cases, areas of quartz clearly show the outlines of included ghost-grains, the two portions being in optical continuity with one another. This suggests that the peculiar interlocking of the quartz grains is due to a process of cementation with silica.

VI. Source of the Xenoliths.

The dolomitic xenolith was probably derived from beds lying at no great depth below the limestones which are seen to be cut by the dyke. About 220 feet below these limestones are the Daviesiella Beds, so named from the presence of the large brachiopod *Daviesiella llangollensis* (Dav.) (10). These beds extend down to the base of the Wye Valley section, and they include numerous dolomitized limestones. It seems very probable that the xenolith under consideration was brought up from these beds.

The four sandstone xenoliths cannot be referred to any beds above the base of the Wye Valley section. An examination of specimens in the collection of the Geological Survey yielded a sandstone of which the mineral content and texture are identical with those of the xenoliths. This sandstone is from the Carboniferous Basement Beds at Melin Gwynyp south of Llandulas in Denbighshire. In thin section (Geol. Surv. E16814) it shows quartz, orthoclase (somewhat altered), microcline and plagioclase in a fresh condition, biotite, muscovite, and magnetite. The quartz preponderates considerably over the felspars. The texture is identical with that shown by the sandstones of the xenoliths ; quartz grains interlock with the same accuracy and partially encircle felspar grains, whilst the original quartz grain outlines are easily detected as they are frequently enveloped by a thin pellicle of iron oxide.

Another rather coarser sandstone from approximately the same horizon and the same locality (Geol. Surv. E16815) shows small rounded fragments of quartzite, and it was of interest in this connection to observe quartz grains apparently derived from quartzites in a section of one of the xenoliths (D 4 in the author's collection).

In Derbyshire, beds of sandstone are unknown in the Avonian succession, but the base of the latter is nowhere exposed. The sandstone xenoliths were carried to their position by the rising magma from some horizon below the lowest beds seen. The sandstones of the xenoliths are identical with the Carboniferous Basement sandstone of Melin Gwynyp in just those characters which render them peculiar, namely, the presence of fresh felspars, especially potash members, and in the remarkable intergrowth of the quartz. This would suggest indeed that the Carboniferous succession in Derbyshire has basement beds similar in their lithology to those in North Wales, which Neaverson refers upon stratigraphical grounds to the top of Vaughan's " Seminula " Zone (11). Jackson has referred the lowest beds in the Wye Valley section to the Seminula Zone also (12). If the base of the Carboniferous in North

Wales and in Derbyshire is comparable in horizon, then the basement beds from which the xenoliths were derived cannot lie at any great depth at the centre of the dome in the Topley Pike region of Derbyshire.

Recently, the author has recorded the occurrence of fragments of *Archaeosigillaria vanuxemi* (Göpp.) in the lowest beds of the Wye Valley section (10). In other areas where this plant has been noted, it appears to occur close to the local base of the Carboniferous series, whence it would be derived from a not-very-distant sinking landmass. Hence in Derbyshire, the Carboniferous basement beds would appear to lie at no great depth below the base of the Wye Valley section.

In conclusion, I wish to thank Dr. L. Hawkes and Mr. S. I. Tomkeieff for help and criticism, Dr. T. N. George for his kindness in preparing sections of Carboniferous Basement sandstone from North Wales, and Dr. H. Dighton Thomas for reading through the manuscript. To Mr. W. A. Deer, of Manchester University, I am grateful for time and patience spent upon the analysis of the tholeiite. Thanks are also due to Imperial Chemical Industries, Ltd., for permission to examine the cutting at Buxton Bridge.

LIST OF REFERENCES.

(1) Geikie, Sir Archibald. *Ancient Volcanoes of Great Britain*, ii, 1897, 14.

(2) Arnold-Bemrose, H. H. "The Toadstones of Derbyshire; their Field-Relations and Petrography": *Quart. Journ. Geol. Soc.*, lxiii, 1907, 281.

(3) Sibly, T. F. "The Faunal Succession in the Carboniferous Limestone (Upper Avonian) of the Midland Area (North Derbyshire and North Staffordshire)": *Quart. Journ. Geol. Soc.*, lxiv, 1908, 39, fig. 2.

(4) Tomkeieff, S. I. "On some chloritic minerals associated with the basaltic Carboniferous rocks of Derbyshire": *Min. Mag.*, xxi, 1926, 78–9.

(5) Campbell, R., and Lunn, J. W. "Chlorophaeite in the dolerites (tholeiites) of Dalmahoy and Kaimes Hills, Edinburgh": *Min. Mag.*, xx, 1925, 436–8.

(6) "Tertiary and Post-Tertiary Geology of Mull, etc.": *Mem. Geol. Surv.*, Scotland, 1924, 17.

(7) Walker, Frederick. "A tholeiitic phase of the quartz-dolerite magma of Central Scotland": *Min. Mag.*, 1930, 370.

(8) Holmes, A., and Harwood, H. F. "The age and composition of the Whin Sill and the related dikes of the north of England": *Min. Mag.*, xxi, 1928, 519–520.

(9) —— "The tholeiite dikes of the North of England": *Min. Mag.*, 1929, 18.

(10) Cope, F. W. "The Lower Carboniferous Succession in the Wye Valley Region of North Derbyshire": *Journ. Manchester Geol. Assoc.*, i, pt. 3, 1933, 125–145.

(11) Neaverson, E. "Faunal Horizons in the Carboniferous Limestone of the Vale of Clwyd"; *Proc. Liverpool Geol. Soc.*, xv, pt. ii, 1929, 116.

(12) Jackson, J. W. "On the Occurrence of *Daviesiella llangollensis* (Dav.) in Derbyshire": Geol. Mag., lix, 1922, 461–8.

The Petrology of the Warren House Series, Malvern.

By John I. Platt, M.Sc., F.G.S., University College of Wales, Aberystwyth.

THE Warren House Series, Malvern, consists of Pre-Cambrian volcanic rocks into which small dykes and possibly some sills of dolerite are intruded. The object of this present paper is to describe the petrology of the rocks, and also certain alterations which have occurred in them since their formation.

The series crops out near the centre of the Malvern range, and is bounded on the east by the Malvern Fault, which brings up Triassic rocks (Keuper marls and sandstones) against the Pre-Cambrian. On the other sides, rocks of the Malvernian Series are in contact with the volcanic rocks, and part of the junction is faulted, e.g. in the north and north-west. In the south of the area, around Foxhall farm, there is a low-lying tract of country covered with superficial deposits, south of which a small exposure of Warren House rocks has been discovered, and therefore it can be assumed that the volcanic series underlies the greater part of this area.

Numerous references to these rocks occur in geological literature, and the following have contributed papers bearing upon the geology of the area: Professor J. Phillips (1848), Dr. Holl (1865), Rev. J. H. Timins (1867), F. Rutley (1887), Charles Callaway (1880, 1887, 1889), Professor A. H. Green (1895), H. A. Acland (1894, 1898), Professor T. T. Groom[1] (1900, etc., 1910), and J. I. Platt (1924).

THE VOLCANIC ROCKS.

The volcanic rocks consist of lava flows with associated fragmental rocks, but the origin of all the latter is somewhat obscure, for the rocks as a whole are highly fractured and many are porphyritic, so that differential weathering frequently gives to a normal flow the appearance of a fragmental rock. True pyroclastic rocks have, however, been located and probably much of the doubtful material is pyroclastic in origin. The whole suite of volcanic rocks is one rich in soda, while soda-rhyolites, keratophyres, and spilites have been identified. Rocks of the same type vary considerably in specific gravity owing to varying degrees of epidotization of them. This alteration is interesting, and will be considered in more detail later.

The Rhyolites.—The most useful subdivision of the rhyolites, both in the field and in the laboratory, depends upon the presence or absence of phenocrysts. Most of the rocks have a pale reddish colour, duc in part to the felspars, but principally to haematite staining, the latter being more pronounced in rocks near the eastern (Trias) boundary, suggesting the transference of the iron oxide from the adjacent Triassic rocks by the action of meteoric waters. Those rhyolites not stained by haematite show the usual bleaching caused by weathering. In addition, both types contain secondary epidote in varying amounts, which gives a greenish tinge to many of the rocks.

---

[1] Professor T. T. Groom gives details of the bibliography of papers on the Warren House Series in *Q.J.G.S.*, lvi, 1900, 140.

The non-porphyritic type is a compact "flinty" rock, generally somewhat darker in colour than the other type. Only in occasional specimens is any indication of flow seen. Under the microscope the groundmass of the porphyritic type is indistinguishable from the non-porphyritic type. It is microcrystalline, consisting of an intergrowth of quartz and felspar, while indications of isotropic glass are very rare. The felspar is untwinned and is orthoclase. Good spherulites occur occasionally, but the typical texture of these rhyolites is micrographic, with a tendency toward the formation of spherulites. Small lath-shaped crystals of plagioclase felspar, which show simple twinning, can be distinguished within the groundmass of a few specimens, and the occurrence of these indicates a slight variation in type. The intergrowth varies rapidly in grain, even within the same microscope slide, and the coarser parts are richer in quartz, while in some cases epidote is concentrated within them. These show a certain amount of secondary silicification, epidote being produced at the same time, for veins of quartz and epidote cross, or terminate at, these coarse patches and the size and characters of the two minerals in both situations are similar.

The phenocrysts consist of quartz and felspar. The quartz is rarely euhedral, but is usually rounded, with indistinct borders. Many of the quartz phenocrysts are quite grey in colour, due to vast numbers of inclusions, the majority being liquid, of which a number show the presence of gas bubbles, while others are small acicular or rectangular crystals. The felspar phenocrysts are nearly always anhedral and also have indistinct margins. They are fresh and often fractured. Some of them are orthoclase, which mineral is usually untwinned and often shows distinct cleavage cracks, while there are others which are almost certainly anorthoclase. These are similar to the orthoclase phenocrysts in form and when examined in ordinary light, but they have the optical properties of anorthoclase and under crossed Nicols, show a very fine cross-hatching. Approximately one-half of the felspar phenocrysts are plagioclase crystals, which show repeated twinning after the Albite Law, the Pericline Law, or both. They have a maximum extinction angle of from 5° to 16°, with a refractive index less than that of the Canada Balsam; they are, therefore, varieties rich in soda, being nearly pure albite, having an approximate composition of Ab_9An_1. As already stated, all the phenocrysts show indistinct borders, and there surrounds most of them a narrow zone of intergrowth with the groundmass, while many of the quartz crystals contain inclusions of portions of the groundmass. This phenomenon probably indicates that the crystallization of the phenocrysts was completed after extrusion, and further suggest that there has occurred a form of reaction with the groundmass, which has an eutectic composition, causing a certain amount of re-solution of the phenocrysts.

In one or two places, rhyolites containing small cognate xenoliths of the more basic types were seen. One outcrop on Broad Down consists of a rhyolite, in which flow structure can be seen in hand specimen, while the rock also contains small xenoliths of keratophyre, which also can be seen in hand specimen.

Primary mafic minerals are absent in the rhyolites, but there is ample evidence which suggests that femic material undoubtedly plays a part in the constitution of the groundmass of some, if not all of them ; in fact, it is doubtful whether any were entirely free from mafic minerals when originally extruded. Accessory minerals are rare and comprise a few grains of apatite, magnetite, and an occasional small colourless zircon.

The secondary changes which have taken place are important, and vary considerably in different rocks. In addition to the secondary quartz and epidote, chlorite, calcite and haematite also occur. The calcite is probably all due to infiltration, as is much of the haematite, although some of the latter is due to oxidation of the magnetite. The chlorite which occurs in the coarser patches and is associated with the epidote and haematite is probably the result of the decomposition of the mafic constituent of the groundmass. The epidote is the most important secondary mineral, inasmuch as it occurs in all the rocks of the Warren House Series, either in veins, amygdules, or disseminated throughout the rock. It is found associated with the secondary quartz, and it appears to have been formed by hydrothermal processes similar to that of saussuritization in which the felspars and the mafic constituents have played a part. Moreover, as the epidote is associated with the groundmass and only in one or two cases with the phenocrysts, it is the felspathic constituent of the former which has suffered and not the felspar phenocrysts, for except in one or two crystals, the felspars are remarkably fresh, and show no signs of kaolinization or other forms of alteration. From their perfectly fresh character and their intergrowth borders, I consider the phenocrysts of albite to be pyrogenetic, and that the epidote does not represent calcium set free by albitization of primary calcium-felspars, but, as stated above, has been formed by the alteration of the felspathic and femic constituents of the groundmass.

The keratophyres.—These rocks are greenish-grey in colour, and fresh fractures have a dark rough surface. Sometimes they are vesicular, the vesicles being filled with chlorite, calcite, epidote, quartz, or chalcedony. As a group they have suffered greater decomposition than the more acid lavas. They are characterized by euhedral (generally lath-shaped) or subhedral felspars, which vary in size from ·04 to ·4 mm. in length, and which give a trachytic texture to the rock. The differences in size of the felspars cause variations in the grain of the rocks. Although orthoclase occurs, most of the felspars are plagioclase showing simple twinning, while larger crystals show repeated twinning. The maximum extinction angle varies from 3° to 15°, and the refractive index is less than that of the Canada Balsam, so the felspars here also are albitic (approximate composition Ab_9An_1). Quartz is generally present, but much of it is secondary. Many rocks are very rich in magnetite, which is always present ; it occurs in cubes, and is obviously primary. The mafic constituent is generally chlorite, but some small crystals of primary augite were identified. The chlorite, most of which is secondary after the augite, was found in all the keratophyres examined. Other secondary minerals are epidote, sphene, calcite, kaolin, and haematite. Epidote is very common, and occurs filling vesicles, and also disseminated throughout the rocks.

The keratophyres show a wide range of variation. A rock which crops out close to the north-western boundary, near the col above Clutter's Cave, is very rich in calcite, due to infiltration. A rock on Hangman's Hill indicates rapid cooling, for it is very fine-grained, and consists of a glassy base in which are small lath-shaped soda-felspars as well as magnetite and chlorite. A dark-coloured vesicular rock, also from Hangman's Hill, shows interesting secondary alteration of the felspars. The groundmass of the rock is glassy, and in it there are three sets of felspars, some very minute, others ·2 mm. long, and a third set ·7 mm. long. The smallest crystals exhibit variolitic habit and have ragged ends, but the larger crystals are euhedral and so grouped as to give a glomeroporphyritic texture. They show decomposition into quartz and epidote, the latter occurring as radiating crystals, while the remaining parts of the crystals are perfectly fresh felspars which show no signs of alteration.

A characteristic of the keratophyres, especially around the southern end of the inlier, is that they are veined with a lighter coloured rock. In some places the veins are very numerous and, on examination, are found to be very fine-grained non-porphyritic rhyolite.

The spilites.—There are at least two distinct varieties of these rocks, a sub-ophitic type, which approximates to the keratophyres, and a variolitic type. A good example of the latter forms the crags in which Clutter's Cave has been cut. Both types are fine-grained in hand specimen, and a fresh fracture shows a rough surface which, in the variolitic type, is purple in colour, but in the other type is a dark grey. The rocks, where they form small outcrops on the hillsides, are massive and jointed, but in the large old quarry on the eastern side of Hangman's Hill overlooking Dales Hall, they exhibit good pillow structure.

The variolitic spilite is vesicular and glassy, the vesicles being filled with either epidote or a pale green isotropic glass. The epidote is either massive or occurs as radiating needles associated with quartz. Some of the highly vesicular specimens show excellent flow structure and contain a large proportion of glass. The most important primary mineral in the rocks is felspar. The felspars occur as hair-like crystals, and it is these which give the variolitic texture to the rock ; a few, however, are microporphyritic, but these unfortunately are so altered, that only traces of their original twinning is seen, nevertheless they are similar to some of the altered felspars in the keratophyres. The hair-like crystals are also considerably altered, but here and there simple twinning can be identified, while the altered crystals have ill-defined boundaries and consist principally of granular epidote. Epidote, associated with quartz, also occurs in the vesicles, while magnetite, haematite or calcite are also present. No pyrogenetic augite was seen, but a little chlorite, which may be secondary after pyroxene, occurs.

The sub-ophitic spilites consist essentially of plagioclase felspar and augite, but contain little, if any, glass. The felspars are lath-shaped, euhedral crystals or much smaller hair-like crystals ; they often show secondary silicification and rare ones, which were fresh enough to be tested, had a small extinction angle, and there seems little doubt that they are similar in composition to those of the keratophyres. The augite is a pale brown variety, with well-developed prismatic cleavage and occurs as small subhedral crystals or as grains. The texture of the rock is sub-ophitic, while the hair-like felspars suggest a variolitic texture. Primary magnetite occurs and sometimes plays an important part in the rock ; while the usual secondary minerals, epidote, chlorite, magnetite, and haematite, are also present, some rocks being very rich in chlorite, and others very rich in epidote.

The Pyroclastic Rocks.—Pyroclastic rocks are not abundant in the area, but those which are found occur at varying horizons in the series. No fragments of rocks or minerals, other than those found in the volcanic suite or of secondary origin, were found in these rocks, which, moreover, generally contain fragments of one rock type only. They vary from fine tuffs to coarse breccias. A good rhyolitic breccia occurs on the south-east side of Broad Down, near the 700-foot contour. It is composed of fragments of both types of rhyolites in a siliceous matrix rich in haematite. Several tuffs are exposed in the cutting for the waterworks' footpath, and these vary in grain, some being almost entirely fine dust, while others contain isolated fragments of quartz, badly decomposed felspar, magnetite, and rhyolitic and keratophyric fragments in a dark coloured matrix, rich in chlorite and iron ore. In one specimen from this locality, haematite formed the greater part of the matrix ; while another, a calcareous tuff, was mistaken by earlier workers to be a limestone. This rock is thickly veined with calcite, which also forms the bulk of the matrix.

At the extreme north-eastern corner of Broad Down, near the Trias boundary, several pyroclastic rocks occur. In them, most of the fragments are keratophyric, although a few are rhyolitic, and possibly some of the badly weathered parts may be spilitic. Professor

V. C. Illing pointed out to me an interesting band of fragmental rock in the large old quarry overlooking Dales Hall. As already stated, the rocks in this quarry are spilites showing good pillow structure. The band of fragmental rock is intensely weathered, and is parallel to the dip of the associated lavas, while its upper surface is clearly marked. The overlying rocks appear also to be fragmental, but this is due to fracturing and weathering, the rocks being very badly weathered variolitic spilite. The rocks below this junction, on the other hand, are true pyroclastic rocks, for among the fragments of weathered variolitic spilite are small badly weathered felspar phenocrysts. All the rocks in and around the band show intense decomposition, but this is due almost entirely to weathering subsequent to their formation, for in the lower breccia, the fragments are themselves fractured and weathered along the fracture-planes. There has been a certain amount of movement along the band, for the upper junction shows slickensides, but signs of the movement cannot be traced beyond the quarry.

THE INTRUSIVE ROCKS.

The Dolerites.—The dolerites occur as intrusions into the lavas in various parts of the area. They are dark green in colour, and show ophitic texture, which, along with the constituent felspar and augite, can be easily identified in hand specimen. In several parts of the area a modified form of the rock occurs, and this is an epidiorite, for most of the augite has been changed to uralite, and epidote is also an important mineral.

Under the microscope, the fresh ophitic dolerite shows remarkably fresh augite, pale brown in colour, and with the usual cleavage and optical properties. In some cases it is decomposed to chlorite when the latter mineral forms good pseudomorphs. Some serpentine occurs. This is quite distinct from the chlorite, shows mesh structure, and has apparently been formed from olivine, for it has the characteristic olivine shape, and is associated with secondary magnetite. No fresh olivine, however, was found. The felspars are euhedral and are enclosed either partially or entirely by the augite, giving ophitic texture. They are seldom fresh, but here and there repeated twinning can be recognized, and those which could be measured had a maximum extinction angle of 30°, indicating a plagioclase of approximate composition of $Ab_{45}An_{55}$. The alteration of the felspars occurs in patches, being changed into epidote, sericite, and secondary quartz. The usual iron ores are present, viz. magnetite, pyrite, ilmenite, and haematite. The ilmenite is well marked in some specimens, where it is changed in part to leucoxene. Epidote also occurs in veins, while a varying amount of calcite infiltration is common.

The epidiorites consist of plagioclase felspar, uralite, and iron ores, and are distinctly ophitic. The uralite is fibrous and has epidote and haematite between the fibres. Being formed from augite, it usually occurs as pseudomorphs after that mineral, and exhibits pleochroism from green to yellowish-green. Some unchanged augite was identified in some of the specimens. Chlorite also occurs, and this likewise is probably secondary after augite. The plagioclase felspars are also badly weathered. They are subhedral or euhedral, show repeated twinning, and have a maximum extinction angle of 26° (composition approximately $Ab_{55}An_{45}$). They are frequently altered, being in part kaolinized, while epidote occurs as grains within the crystals, and is sometimes associated with sericite and secondary quartz. The rocks are rich in iron ores, magnetite, ilmenite, and haematite, while a few crystals of apatite occur. As the name indicates, the rocks are much altered dolerites, and in some parts of the intrusions the alteration has proceeded to such an extent that an epidote-uralite rock has been formed.

Although the dolerites and the epidiorites have certain points of similarity, such as their texture and the similarity of their mineral composition when fresh, which suggest that they are varieties of the same set of intrusions, the marked differences between their present characters possibly indicates that the epidiorites were intruded at a much earlier period than the fresher dolerites.

SUMMARY.

The Warren House Series consists of lavas which belong to a sodic suite, being rhyolites, keratophyres, and spilites. The rhyolites have a fine-grained micrographic groundmass, and some contain phenocrysts of quartz, orthoclase, anorthoclase, and plagioclase felspar. Epidotization of the rocks has occurred, but it is the felspathic and femic constituents of the groundmass which have suffered alteration and not the felspar phenocrysts, the action not being intense enough to affect the latter. The keratophyres consist essentially of small lath-shaped albite crystals which give a trachytic texture to the rock. The spilites are more basic, vesicular, and variolitic or sub-ophitic in texture, while some of them show pillow-structure in the field. The keratophyres and the spilites also exhibit varying degrees of epidotization. Pyroclastic rocks are not very common, but a few interesting varieties have been noted. Intrusions of dolerite occur within the lavas. One type is an ophitic dolerite, which when fresh probably contained olivine. Another type is now an epidiorite. Both these types have been epidotized, the epidiorite to such an extent that it passes into an epidote-uralite rock in places.

REVIEW.

THE COUNTRY AROUND CIRENCESTER. By LINSDALL RICHARDSON, with contributions by Professor J. A. HANLEY and H. G. DINES. *Mem. Geol. Survey.* Explanation of Sheet 235. 1933. Price 3*s.* net.

THE title of this memoir and the name of its author are sufficient to indicate that it will be an indispensable part of the library of any geologist interested in the Jurassic System. Those who have been using the author's *Moreton in Marsh* memoir, published in 1929 (see review in this Magazine, LXVII, 526–8), will have been looking forward with impatience to the promised extension into the sheet to the south. They will have grown accustomed to expecting an exceptionally high standard, and they will not be disappointed. As usual, everything is here: minute descriptions of every exposure—quarry, well, ditch, or cattle track—with the most modern palaeontological records and comments as to correlation, the whole lucidly described and arranged in such a way that it forms a complete picture of the geology and anything can be found at a moment's notice. Dr. Welch's photographs again add a welcome embellishment.

In the Cirencester area by far the most important surface formation is the Great Oolite Series, and the description of it and the unravelling of its intricacies take up more than a third of the memoir. Contrary to the opinion of Buckman, we learn that the local Fuller's Earth is a continuation of that above the Fuller's Earth Rock of the Bath district. The Stonesfield Slate Series and the freestones to which it locally gives rise are for the first time distinguished from the stratigraphically higher Taynton Stone. It is curious that although the Taynton Stone was a renowned freestone at least from the twelfth to the eighteenth centuries (as shown by its use in buildings at Oxford) all the great quarries are now derelict, while the only large quarry at present working continuously and turning out faced and cut building-stones in quantity—namely, Fosse Quarry, Farmington—is worked in freestone forming part of the Stonesfield Slate Series. This freestone is capped by a bed swarming with *Ostrea acuminata*, while the Taynton Stone is above the range of *O. acuminata* and upon it always follow the Hampen Marly Beds, swarming with *O. sowerbyi*.

The White Limestone division is described in all its bewildering and palaeontologically so extraordinarily interesting facies of brachiopod-marls, coral-beds, Dagham Stone, beetroot-stone, *Nerinaea*-beds, *Ptygmatis*-rock, etc. The complete sections in the Chedworth railway-cuttings, which are here redescribed, provide a basis for the first thorough attempt at a correlation of the numerous scattered exposures. The position of the famous Fairford Coral Bed is at last finally settled.

Perhaps the most important contribution of the memoir to stratigraphy is the part dealing with the Forest Marble or Wychwood Beds and Kemble Beds. Although it has been found expedient to retain only one colour for these two subdivisions on the map, care has been taken to demonstrate how in the Kemble Beds, which lie below the horizon of the Bradford Clay fauna, the "White Limestone" and "Forest Marble" facies alternate. Where the "Forest Marble" facies is developed it is often difficult and sometimes impossible to be sure to which subdivision the rock in any particular quarry should be assigned. Indeed there is one quarry (Pilham Lodge, near Fairford), which will long provide food for thought and further investigation. The author considers that the 21½ feet of rock exposed belongs to the Kemble Beds, but just above the middle are found brachiopods which appear to be the typical *Epithyris marmorea* (Oppel) elsewhere found only at Corsham, Wiltshire, at the top of the supposedly authentic Forest Marble.

Widespread surfaces of erosion are noted at the base of the Kemble Beds and at the base of the Wychwood Beds, often associated with pebbles and channelling. In one locality (Sunhill, near Fairford) there is at the base of the Kemble Beds 1 foot of loosely-compacted subangular limestone gravel, probably unique in the Jurassic rocks of Britain. A gradual easterly attenuation of the Wychwood Beds is interpreted as probably due to posthumous movement along the prolongation of the Vale of Moreton Axis. Before this can be proved, however, it will be necessary to explain the similar attenuations farther east, in Oxfordshire and Northamptonshire.

An important chapter on the Inferior Oolite completes the picture, begun in the Moreton memoir, of the easterly overlaps of the various subdivisions of the formation as they are traced from the North Cotswold syncline across the Vale of Moreton Axis. There are also short notes on the Lias and the Cornbrash.

The memoir concludes with a useful summary of the superficial deposits, largely by Mr. H. G. Dines, and the usual chapter on economic geology, with, in addition, a section on agriculture by Professor Hanley. Although Mr. Dines considers it unwise to correlate the superficial deposits with those of other localities, he puts forward a "Sequence of Events" which, if correct, must have a much more than local application.

W. J. A.

CORRESPONDENCE.

RAISED BEACHES IN GOWER.

SIR,—It is evident from Dr. George's letter in the June number of the GEOLOGICAL MAGAZINE that he has misunderstood my remarks in an earlier letter, and it is particularly desirable to remove these misunderstandings, because the district of Gower is most important in Quaternary geology.

The first of these misunderstandings is concerned with the molluscan assemblage in Dr. George's *Patella* Beach. My point is not that the forms listed from this beach cannot be found together washed up on the present shore, but that that is not the association which would be expected near the snouts of valley glaciers. Both the absence of cold forms of *Astarte, Mya* and *Chlamys,* as well as the presence of *Ostrea edulis* and *Chlamys varia,* suggest that this *Patella* Beach cannot be strictly contemporaneous with the period of formation of sea-ice or icebergs. Therefore the erratics have been introduced into the district before the formation of the *Patella* Beach, and the term " pre-Glacial " is inadmissable. Dr. George would be far safer to retain some such term as " *Patella* Beach of Gower ", although this expression may not be ideal.

The second misunderstanding relates to the heights at which raised beaches are found, and the use of the height of a raised beach in a stratigraphical sense is certainly to be condemned. This practice, which was used by me in 1927, was definitely abandoned by me when describing the raised beach at Portland in 1930, and in the light of my work at Portland it is now meaningless to use such terms as " 25 foot beach " and 50 foot beach " without further qualification, and the term Portland Raised Beach was adopted to describe the feature at that place. It is probable that these terms are also equally meaningless as applied to Gower, and therefore Dr. George only causes unnecessary confusion in discussing the Gower beaches in this terminology. I certainly agree that the main raised beach of Gower, at about 30 feet, is not post-Glacial.

As regards Dr. George's statement that I have assigned both Mousterian and Neolithic dates to some particular raised beach, I have never described a " Neolithic Raised Beach " from Gower or from anywhere else. Presumably Dr. George is referring to my original suggestion of a " post-Glacial " date for the " 25 foot beach " in Scotland, but if he believes that that supposed feature is everywhere of Neolithic age in Northern Britain he has failed to understand the writings of Dr. Wright and others on that subject.

D. BADEN-POWELL.

OXFORD.
17th July, 1933.